"SCREENING AND SELECTION OF EFFICIENT VESICULAR ARBUSCULAR MYCORRHIZAE (VAM) FOR AONLA (*Emblica officinalis* Gaertn)."





Submitted to the



BUNDELKHAND UNIVERSITY JHANSI (UP)

In fulfilment of requirements for the degree of DOCTOR OF PHILOSOPHY

In

BOTANY

By

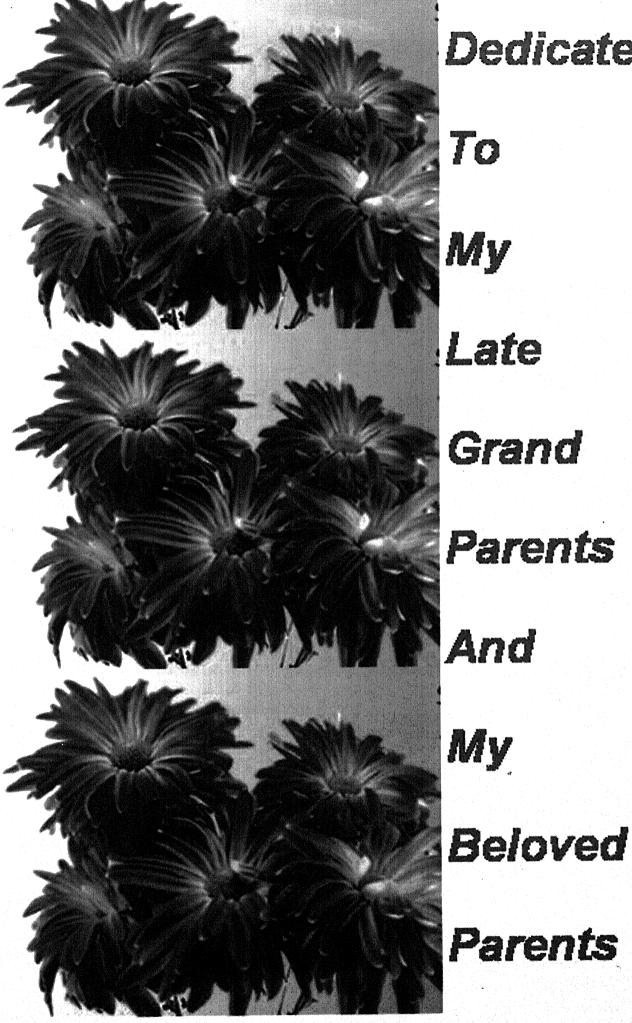
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2007



Dedicated To My Late Grand **Parents** And My

Declaration

I hereby declare that the thesis entitled "Screening and Selection of Efficient

Vesicular Arbuscular Mycorrhizae (VAM) for Aonla (Emblica officinalis

Gaertn)." being submitted for degree of Doctor of Philosophy to the

Department of Botany, Bundelkhand University, Jhansi (UP) is an original

piece of work done by me under the supervision and guidance of Dr. Anil

Kumar, Senior Scientist, NRCAF, Jhansi and to the best of my knowledge, any

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Place: JHANSI

Dated: 30.7.07

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This is to certify that the work embodied in this thesis entitled "Screening and Selection of Efficient Vesicular Arbuscular Mycorrhizae (VAM) for Aonla (Emblica officinalis Gaertn)." being submitted by Ms. Shahnashi Hashmi, for the award of degree of Doctor of Philosophy to the Bundelkhand University, Jhansi, has been carried out under my supervision and guidance, that the work, embodied has not been submitted elsewhere for the award of any other degree and is up to the mark both in its academic content and the quality of presentation.

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This is to certify that the thesis entitle "Screening and Selection of Efficient Vesicular Arbuscular Mycorrhizae (VAM) for Aonla (Emblica officinalis Gaertn)." submitted by Ms. Shahnashi Hashmi to the Department of Botany, Bundelkhand University, Jhansi, for the award of the degree of Doctor of Philosophy is a record of bonafide research work carried out by her under my supervision and guidance. Ms. Shahnashi Hashmi has work on this problem for a period of more than three years and the thesis in my opinion is worthy of consideration for the award of the degree of doctor of philosophy in Botany in accordance with the regulation of this centre and Bundelkhand University, Jhansi. The results embodied in this thesis have not been submitted to any other university and institution for the award of any degree.

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Jhansi

(Shahnashi Hashmi)

July, 2007

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Introduction

INTRODUCTION

Aonla (*Emblica officinalis* Gaertn.) is an important minor fruit crop of Indian origin. It can be grown in salt affected soils with high pH and poor fertility of semi-arid regions. It occupies an area of 20,000 ha with production of two- lakh metric tons and productivity of 15-20 t ha⁻¹ (Pathak, 2000). Aonla is widely grown in Uttar Pradesh, Maharashtra, Gujarat, Haryana, Punjab, Tamilnadu, Andhra Pradesh and Karnataka, wherein Uttar Pradesh alone contributes for 60% production. Aonla fruits have special significance due to their high nutritive value and rich medicinal properties. It is a rich source of vitamin-C and is widely used in Unani and Ayurvedic systems of medicine. Aonla fruits are utilized for processing several value-added products like preserves and pickles. It is also an important ingredient of Chyavanprash, Trifla, Amla ki Rasayan and powder, which are good for diabetic patients.

Plant roots provide an ecological niche for many of the microorganisms that abound in soil. German Botanist A.B. Frank (1885) introduced the Greek word *mycorrhiza* to scientific terminology, which literally means "fungus root". In natural ecosystems much of the root system can be colonized by mycorrhizal fungi. Colonization is restricted to the root cortex and does not enter the vascular cylinder. The symbiosis is so well balanced that, although many of the host cells are invaded by the fungal endophyte, there is no visible tissue damage and under certain conditions it enhances the growth and vigor of the host plant. Because most economically important plants form mycorrhizae, the subject is currently attracting much attention in agricultural, horticultural and forestry research. Three general types of mycorrhizal associations have been recognized:

- Vesicular arbuscular mycorrhizae (VAM)
- Ectomycorrhizae (ECM)
- Ericoid or ectendo-mycorrhizae

Over a long period of time, specific climate and edaphic factors have been responsible for the selection of the distinctive types of mycorrhizae being associated with defined vegetation types. Species with ericoid mycorrhizae are predominantly present in soil of high altitudes and latitude, ecto-mycorrhizae species predominant in forest ecosystem of intermediate altitudes and latitudes and plants with VAM dominate herbaceous and woody plant communities on mineral soils at low latitudes (Read, 1991). Present study consisted of VAM fungi of Aonla and some other minor fruits due to their common occurrence in Bundelkhand region.

Mycorrhizae have received considerable attention in recent years because mycorrhizal plants have several advantages over non-mycorrhizal plants. Mycorrhizal associations are generally considered to benefit host plants by enhancing mineral nutrient acquisition, especially with regard to phosphorus, which is relatively immobile in the soil. Mycorrhizal fungi have also been found to enhance water transport in plants (Safir et.al., 1971), decrease transplant injury (Menge et.al., 1978), promote establishment of plants in wasteland and reduce the vulnerability to diseases caused by soil borne pathogens (Schonbeck, 1979). As already mentioned Aonla is hardy in nature and gaining popularity for utilizing marginal and degraded lands in arid and semi-arid regions of our country. Screening and selection of efficient VAM species for Aonla will provide suitable mycorrhizal strains to obtain better quality plants. It is expected that more economic returns to the extent of 20-30% will be available to the target groups, without any significant increase in input cost. Therefore, the present study was taken up with broad objective to identify suitable vesicular arbuscular mycorrhizal (VAM) species for Aonla and some other minor fruits viz., Ber (Zizyphus mauritiana Lamk.), Chironji (Buchanania lanzan Spr.) and Lasoda (Cordia myxa Roxb.). To achieve this, following specific objectives were set:

Objectives:

- Identification of sites with good mycorrhizal plants in local orchards and nurseries.
- Identification of VAM species, which occur in abundance at identified sites.
- Studies on relationship between soil parameters and VAM species at marked sites.
- Culturing of common VAM species.
- Screening of VAM species for vigorous plant growth under nursery conditions.

Review Of Literature

REVIEW OF LITERATURE

Plant roots provide an ecological niche for many of the microorganisms that abound in soil. German Botanist A.B. Frank (1885) introduced the Greek word mycorrhiza, which literally means "fungus root," In natural ecosystems much of the root system can be colonized by mycorrhizal fungi. Colonization is restricted to the root cortex and does not enter the vascular cylinder. The symbiosis is so well balanced that, although many of the host cells are invaded by the fungal endophyte, there is no visible tissue damage and under certain conditions it enhances the growth and vigor of the host plant. Because most economically important plants form mycorrhizae, the subject is currently attracting much attention in agricultural, horticultural, and forestry research. There are different types of mycorrhizae. The main types of mycorrhizae and the host plants in which they are commonly associated are given in Table 2.1. As the present study was concerned with vesicular arbuscular mycorrhizae (VAM), information available in literature on its benefits, occurrence, taxonomy, ecology and culturing techniques was reviewed and is being presented here, in short.

Table 2.1 Different types of mycorrhizae and their hosts

Host plant/families	
Pinaceae, Fagaceae, Betulaceae,	
Leguminaceae, mostly caesalpinoid	
legumes,	
Salicaceae, Tiliaceae, Rosaceae,	
Juglandaceae, etc.	
Majority of the plants including those	
important in agriculture, horticulture,	
pasture and tropical forests	
Ericaceae and Epacridaceae	
Orchidaceae	
Arbutus and Monotropha	

2.1 Benefits of VAM Fungi

VAM fungi confer following benefits on the host:

- Enhance acquisition of mineral nutrients, especially phosphorus, which is relatively immobile in the soil.
- Enhance water transport in plants, decrease transplant injury and promote establishment of plants in wasteland. Mycorrhizal plants recover better following moisture stress, more efficient in water use and frequently have higher root-shoot ratio than non-mycorrhizal plants.
- Reduce the vulnerability to diseases caused by soil borne pathogens.
- Increase plant growth by 20-30% in terms of bio-mass.
- Enable the plants to grow and survive better under various stress conditions, like those in coal spoils, sand dunes, saline-alkaline soils, eroded-degraded sites and lands polluted by industrial wastes.

2.2 Occurrence

VAM fungi have the widest host range and distribution of all the mycorrhizal associations. It is estimated that about 90% of vascular plants normally establish mutualistic relationship with VAM fungi. VAM fungi have been observed in 1000 genera of plants representing some 200 families. There are at least 300,000 receptive hosts in the world flora (Kendrick and Berch, 1985), and there are about 120 species of VAM fungi (Schenck and Perez, 1987). If the hosts are divided up evenly among the fungi with no overlap in host range, each fungus would have more than 2500 potential partners. We know that host ranges overlap extensively, suggesting that some individual VAM fungi may well have access to thousands of hosts (Kendrick and Berch, 1985).

According to Gerdemann (1975), it is easier to list most plant families that do not form vesicular arbuscular fungi than to list those that do. Families not forming Vesicular arbuscular fungi include Pinaceae, Betulaceae, Orchidaceae, Fumariaceae, Commelinaceae, Urticaceae, and Ericaceae.

Families that rarely form arbuscular mycorrhiza include the Brassicaceae, Chenopodiaceae, Polygonaceae, and Cyperaceae. Families that form both ectomycorrhizae and vesicular arbuscular fungi include Juglandiaceae, Salicaceae, Tilliaceae. Myrtaceae, Fagaceae, and Caesalpiniaceae (Gerdemann, 1975). Important crops with vesicular arbuscular fungi include wheat, maize, all millets, potatoes, beans, soybeans, tomatoes, apples, oranges, grapes, banana, castor, tobacco, tea, coffee, cocoa, sugarcane, mango, asparagus, rubber, cardamom, pepper, etc. Most of the tropical rain forest trees are vesicular arbuscular mycorrhizal (Janos, 1983). Harley (1969) has listed the gymnosperms in which vesicular arbuscular mycorrhizae have been observed. They are found in Pteridophytes (Cooper, 1976) and Bryophytes (Parke and Linderman, 1980). Recently, vesicular arbuscular mycorrhizal colonization has been reported in floating (Bagyaraj et al., 1979) and submerged aquatic plants (Clayton and Bagyaraj, 1984). Usually vesicular arbuscular mycorrhizae are confined to the roots; they have been reported in diverse structures such as the modified leaves of water fern Salvinia cucullata (Bagyaraj et al., 1979), fruiting peg of peanut (Graw and Rehm, 1977) and modified scale like leaves and rhizomes of ginger and canna (Selvaraj et al., 1986).

Vesicular arbuscular mycorrhizae, in addition to their widespread distribution throughout the plant kingdom, are also geographically ubiquitous and occur in plants growing in arctic, temperate, and tropical regions (Mosse et al., 1981). In general, VAM population is more in cultivated soil compared to virgin soil (Mosse and Bowen, 1968). They are mostly seen in the top 15-30 cm of soil, and their numbers decrease markedly below the top 15 cm (Redhead, 1977). They are normally not found in depths beyond the normal root range of plants (Mosse et al., 1981). The distribution of species of VAM fungi varies with climatic and edaphic environment as well as with land use. For example *Acaulospora laevis* is common in Western Australia (Abbott and Robson, 1977) and New Zealand (Mosse and Bowen, 1968) but occurs less

frequently in soils of Eastern Australia (Mosse and Bowen, 1968). Glomus species appear to have widest distribution. Gigaspora and Sclerocystis species are more common in tropical soils. Acaulospora seems to be better adapted to soils with pH <5.0. In fact, certain VAM fungi have been linked to particular kinds of soil: Glomus mosseae with fine textured, fertile, high pH soils; Acaulospora leavis with coarse-textured, acid soils; and Gigaspora species with sand dune soils (Kendrick and Berch, 1985).

2.3 Taxonomy

VAM fungi, being obligate biotrophs, do not grow on synthetic media and hence are classified according to morphological characteristics of the spores formed in the soil. One hundred and twenty species have been described by Schenck and Perez (1987), and they are all grouped in a single family, the Endogonaceae. The family is considered to be in an order of its own, the Endogonales tentatively placed in the class Zygomycetes in the subdivision Zygomycotina (Benjamin, 1979). The seven genera, Endogone, Glomus, Sclerocystis, Entrophospora, Acaulospora, Scutellospora and Gigaspora, presently constitute the Endogonaceae. Of these, only Endogone forms zygospores characteristic of Zygomycetes, while others probably lack sexual reproduction, species of Endogone do not form vesicular arbuscular mycorrhizal association. The other six genera form vesicular arbuscular mycorrhizal associations.

The main features of VAM fungi are summarized by Trappe and Schenck (1982) and Hall (1984). Hall and Abbott (1983) compiled photographic transparencies illustrating diagnostic features of the Endogonaceae. Walker (1983) has suggested a standardized terminology for use in description of endogonaceous spore walls involving a stylized graphic representation of the wall structure ("murograph"). This concept is recommended for future descriptions of new species. Recently, Schenck and Perez (1987) published a manual for the identification of VAM fungi.

Glomus, the most common genus of VAM fungi, has over 50 species which form globose, ellipsoid or rather irregularly shaped spores that range from 20-400 µm. These spores are thick-walled (up to 30 µm), and hyaline, yellow, red-brown, brown or black. Spores are attached to a single subtending hypha (or to two, three, or more in exceptional species) and produced in the soil near plant roots, at the soil surface, or occasionally in roots, and they may form singly, in groups of a few to many, or in large aggregates called sporocarps. Sporocarps are most commonly found in undisturbed forest communities with perennial plants and accumulated organic material. Sporocarpic species, when grown on plants in pot culture, usually produce spores singly or in small aggregates. Some Glomus species (e.g., Glomus lacteum) are not known to form spores in sporocarps, while others form spores outside the plant root only infrequently (e.g., Glomus intraradices). The spores of most species germinate by emergence of a germ tube directly through the subtending hypha.

Sclerocystis species produce chlamydospores that are very similar to those of Glomus, except that they tend to be clavate rather than globose. All sclerocystis species form spores only in sporocarps up to 700 μm in diameter. The spores, which can be up to 125 μm long, develop in a single layer, radially arranged around a central plexus of sterile and sporogenous hyphae. The sporocarps may group together in masses up to several cm in diameter on the soil surface, on leaves, twigs, and mosses. There is no published information on the germination of Sclerocystis spores.

Spores of the genus *Acaulospora* appear to form laterally on the neck of a small thin-walled saccule, called variously a mother spore, a vesicle, a hyphal terminus, a soporiferous saccule, or a sporogenous saccule (Walker, 1987). When mature, the spore does not display a subtending hypha because the vesicular structure that gives rise to it loses its cytoplasm and collapses during development of the spore. The spores are globose or ellipsoid, from <100 to >400 µm in diameter, and hyaline, yellow, or reddish-brown. The

surface of the sporewall may be ornamented with pits, projections of various shapes, folds, spines, or reticulations, and the wall is up to $12 \mu m$ thick. One species of *Acaulospora* is now known to produce sporocarps, but in other species, spores are normally found in the soil of the rhizosphere, *Entrophospora* is more or less similar to *Acaulospora* except that the spore is formed inside the parent hypha just below the vesicle.

Scutellospora spores can be greater than 600 µm in diameter, and the smallest ones are just under 200 µm in diameter. Spores develop terminally on a bulbous hyphal suspensor, which remains attached at maturity and may bear short lateral projections. Spores are usually globose but can be ovoid, obovoid, pyriform, or irregular. Spores are hyaline, white, yellow, pinkish, grey-green, or brown. Spore wall structure is composed of at least two wall groups, with one or more flexible membranous or coriaceous walls in the inner group or groups. The genus is characterized in particular by its mode of spore germination. Germination is by means of one or more germ tubes produced near the spore base from a germination shield formed within or upon a flexible inner wall. Thin walled, knobby, or broadly papillate auxiliary cells (vesicles) are borne in soil on straight or coiled hyphae, formed singly or in clusters. Gigaspora produces spores which are superficially similar to those of Scutellospora spores. The striking differences are the germination of spores, which is by direct growth of one or more germ tubes through the spore wall. It is possible that this genus evolved from Scutellospora (Walker, 1987).

Another fungus, or group of fungi, that forms endomycorrhizae has been referred to in the literature as "the fine endophyte," since its hyphae are <4 um wide, compared to 10-20 µm for typical VAM fungi. This anomalous endophyte has been described as *Glomus tenue*, though it does not resemble the other species of *Glomus*. Its spores are 10-15 µm in diameter, and when young are hyaline and indistinguishable from the vesicles that form in the roots; when mature, however, they are pigmented. Because of their small size as compared to those of other VAM fungi, the spores of *Glomus tenue* are not

often recorded in nature, though mycorrhizae of this type are common, particularly in dry regions.

2.4 Factors Affecting the Development of Mycorrhizae

A. Physical Factors:

Temperature: Temperature has been shown to have a significant influence on colonization and sporulation by VAM fungi under greenhouse conditions. Higher temperatures generally result in greater root colonization and increased sporulation (Furlan and Fortin, 1973). Studying the effects of temperature on VAM establishment, Schenck and Schroder (1974) observed that maximum arbuscule development occurred near 30°C but that mycelial colonization of the root surface was greatest between 28 and 34° C. Daniels and Trappe (1980) observed that optimum temperature for the germination of Glomus and Acaulospora spores is around 20-25°C, whereas Gigaspora had a much higher optima. These studies suggest that increased soil temperature hastens the development of VAM fungi. This may explain the slow development of infection in agricultural crops in temperate soils (Black and Tinker, 1979) where soil temperatures are low compared to tropical soils. Since most species of VAM fungi exist worldwide, it is possible that strains and species may be temperature adapted. This is suggested by the work of Schenck et al. (1975), who found that two isolates of Glomus from Florida germinated best at 34°C, whereas one from Washington had an optimum of 20°C.

Light: VAM fungi obtain their carbon source from the host plant and thus rely on both the photosynthetic ability of the plant and the translocation of photosynthates to the root. Hence, light can strongly affect the development of mycorrhizae. The stimulatory effect of light on the development of vesicular arbuscular mycorrhizae has been shown by Furlan and Fortin (1977). Shading not only reduces root colonization and spore production but also the plant response to VAM fungi (Gerdemann, 1968). Redhead (1975) postulated that day length may play an important role in vesicular arbuscular mycorrhizal development, and this was confirmed by Daft and El-Giahmi (1978).

However, the effect of light on VAM fungi seems to depend on the photosensitivity of the species of host plant (Redhead, 1975). In fact, a photoperiod of 12 hour or more may be more important than light intensity in providing high levels of root colonization, but if suitable day length is provided, increased light intensity may still increase colonization (Daft and El-Giahmi, 1978). It could be particularly interesting to examine this aspect in plantation crops like coffee, cardamom, etc., which are cultivated under shade trees in the tropics.

Water: A continual decline of germination of Gigaspora gigantea in polyethylene glycol from 80% at – 0 MPa to 15% at –10 MPa was reported by Wilson (1984). Glomus caledonicum, Gigaspora calospora and Acaulospora laevis spores showed high germination from –0 to 1.4 MPa, but delayed germination at –2.2 MPa (Tommerup, 1983). These data suggest that more spore germination can probably occur at soil moisture levels at which roots do not normally grow (Bowen, 1984).

VAM fungi occur over a wide range of soil water contents. Colonization has been found in arid regions in xerophytes (Khan, 1974), very wet soils of marshes (Dowding, 1959), and also in free-floating (Bagyaraj *et al.*, 1979) and submerged aquatic plants (Clayton and Bagyaraj, 1984). It was believed earlier that under saturated conditions, O₂ concentration can inhibit VAM spore germination and root colonization (Saif, 1981). Le Tacon *et al.* (1983) observed for spores germinated in air that their subsequent growth was little affected by lack of O₂ until the oxygen tension was below 3%. The recent observations on mycorrhizae in aquatic plants suggest that perhaps in water there is adequate dissolved O₂, and concentrations of toxic substances such as Mn, H₂S, organic acids, etc., developing under anaerobic conditions are probably absent. Soil water may select for certain species of VAM fungi, which adapt to that environment (Manjunath *et al.*, 1981).

B. Chemical factors:

pH: Studies conducted in the laboratory on agar media suggest that good germination of VAM spore occurs between pH 6 and 7, although there are cases of fungi germinating at pH 5 and below as well as pH 8 and above (Sparling and Tinker, 1978). Optima for germination of Gigaspora corraloidea, Gigaspora heterogama, and Glomus mosseae on the agar have been recorded at pH 5, 6 and 7, respectively (Green et al., 1976).

In soil, effects of pH are difficult to evaluate since many chemical properties of soil vary with changes in pH. In soil, more than 40% germination of *Glomus epigeum* spores was found over the pH range 4.8-8.0, the optimum being 7.2 (Daniels and Trappe, 1980). Sparling and Tinker (1978) found no obvious effect of pH on infection in three grassland sites at pH 4.9, 5.9 and 6.2, however, such infection may have been due to different endophyte species. There is some evidence for differences in adaptation of strains and species of VAM fungi to pH. Lambert and Cole (1980) reported that six isolates of *Glomus tenue* differed in their ability to form mycorrhizae at low pH. Daft *et al.* (1975) reported considerable VAM colonization in plants growing in a bituminous mine spoil of pH 2.7. Natural soils of the world cover the pH range 2.8 to >10.0 (Bas Becking *et al.*, 1960). Soil pH may affect the distribution of mycorrhizae in a subtle way.

Phosphorus: The addition of phosphorus affects VAM colonization of roots (Jasper et al., 1979 and Menge et al., 1978). Conclusive recommendations for specific soil P levels for mycorrhizal production cannot be made. There are several reasons for this. First, it is not soil P per se that regulates mycorrhizal colonization, but rather the amount of P absorbed by the host plant (Menge et al., 1978). Second, methods for evaluating available soil P often differ greatly, and plant tissue analysis is a far more reliable method for determining available soil P than most methods that analyze soil. Finally, since host plants vary in their ability to absorb P and mycorrhizal fungi vary in their response to P, each plant – soil – VAM symbiont system must be evaluated separately

(Jasper et al., 1979 and Menge et al., 1978). For example, in one sandy soil, maximum spore production by *Glomus fasciculatum* on sour orange occurred at 50 ppm added P, but this amount of P applied to a different citrus variety (*Troyer citrange*) did not encourage sporulation (Menge et al., 1978).

Tissue P is also not always a good estimate for mycorrhizal colonization because the mycorrhizae themselves influences that factor. It is thought that P influences VAM colonization by affecting concentrations of root carbohydrates (Jasper et al., 1979) or the amount of root exudates (Graham et al., 1981) and for that reason the effects of P concentration may be partially overcome by other factors such as light intensity (Graham et al., 1982). The best indicator for identifying a soil that will provide good VAM colonization appears to be the percentage of P in plants at the time of VAM colonization (Jasper et al., 1979). Recently, Sreenivasa and Bagyaraj (1989) observed that rock phosphate applied at 100 ppm P level resulted in more of infective propagules of Glomus fasciculatum compared to bone meal and superphosphate fertilizers (Clarke, 1981). Long-term application of superphosphate fertilizer (15 years of 150 kg P/ha/yr) was found to result in a population of VAM endophytes that was little affected by subsequent additions of P (Porter et al., 1978). It appeared that P-tolerant strains have developed during the 15-year period of superphosphate application. More work in isolating P-tolerant strains is needed, as they can be used for inoculating high-vielding varieties of field crops and horticultural crops demanding application of heavy doses of fertilizers.

Nitrogen: Hayman (1975) showed that N fertilizers (188 kg N/ha as Nitrochalk) had a large negative effect on the mycorrhizal population. This was confirmed later by Jensen and Jakobsen (1980). Alexander and Fairley (1983) reported reduction in mycorrhizal colonization following application of 300kg N/ha as (NH₄)₂ SO₄. Davis and Young (1985) reported NO₃- salts to be more inhibitory to VAM development than NH⁺₄ salts. These results indicate that

nitrogen contents of soils could greatly influence the distribution and abundance of VAM fungi.

Micronutrients: Micronutrients such as manganese (Mn) and zinc (Zn) inhibit spore germination of mycorrhizal fungi (Hepper, 1979). Zinc and copper (Cu) was shown to inhibit mycorrhizal colonization in clover, onion, maize, soybean and pinto bean (Mosse *et al.* 1981 and Ponnamperuma, 1972). Zinc, copper and manganese applied at the rate of 12, 2, 5 and 40 ppm, respectively, along with Ruakura solution improved mycorrhizal root colonization, sporulation and the most probable number of infective propagules of *Glomus fasciculatum* (Sreenivasa and Bagyaraj, 1988).

Acid soils contain much soluble Al, Mn and Fe and in neutral soils Mn and Fe can be released in large quantities when reducing conditions prevail after waterlogging (Ponnamperuma, 1972). Many soils are grossly polluted with heavy reclaimed site of an old lead mine at Shipham, England and found considerable colonization in white clover growing on soil heavily contaminated with Zn and Cd. This suggests that VAM endophytes can develop strains adapted to particular soil conditions. Hence, one of the prime strategies for reclamation of mine tailings should be the selection, introduction and maintenance of suitable mycorrhizal fungi.

Pesticides: Trappe et al., (1984) have reviewed the effect of pesticides on mycorrhizal fungi and mycorrhizae. Most research with pesticides has been undertaken with soil fumigants, fungicides and nematicides which exhibit a range of activity towards VAM fungi. Fumigation of soil with biocides such as Methyl bromide, Chloropierin, Formaldehyde, Mylone, Vapam and Vorlex effectively kill endophytes in the treatment zone. Fortunately, these fungi reinvade most fumigated soils within several years. Unlike the general biocides, most nematicides such as 1, 3-dichloropene (1,3-D), 1,2-dibromoethane (EDB), 1,2-dibromo-3-chloropropane (DBCP) and some of the organophosphates (Bhenomiphos) and organocarbamates (Aldicarb) at recommended rates exhibit no or a slight inhibitory effect. Interestingly, some

nematicides, such as DBCP and 1,3-D, can stimulate root infection in host plants. This type of response is believed to be due to control of competitive and plant-pathogenic microflora, to possible stimulation of exudates from host plant roots or to other factors.

The systemic fungicides like Thiobendazole, Benomyl and Triadimefon are more toxic to these fungi. Pentachloronitrobenzene, which is not systemic, is also highly toxic. Many fungicides are probably only fungistatic to these fungi (Nemec, 1987). Limited research has been done on the effect of herbicides and insecticides on VAM fungi. Paraquat and Simazine are toxic to these fungi, whereas Trifluralin, Bromacil and Diuron are nontoxic. The insecticides Metsystox and Aldrin differ in their activity on VAM fungi, the former being less toxic than the latter.

Many pesticides contain heavy metals, and the presence of such metals in soils may be responsible for poor germination of these fungi (Hepper and Smith, 1976). In highly acid soils, especially those of the tropics, Manganese and Aluminium may be more soluble and reach concentrations that limit growth of these fungi. Selecting pesticides with no adverse effect on VAM fungi but reducing contaminants in pot cultures will be useful in the maintenance and mass production of these fungi (Menge, 1984).

Salinity: Sodium and chloride ions inhibit spore germination of VAM fungi (Gildon and Tinker, 1983). Bowen (1980) found typical VAM colonization and spores in a soil with more than 5000 ppm chloride. There are several reports of VAM fungi in maritime salt marshes (Mason, 1928). It is not known whether the endophytes involved show a special adaptation to the saline conditions. Bowen (1980) hypothesized that VAM fungi could counteract some forms of soil toxicity by absorbing elements harmful to plants or assisting plant tolerance of high alkalinity or high salinity in tropical soils.

Organic Matter: Organic matter influences soil structure, pH, nutrient profile and water-holding capacity, all of which may directly and/ or indirectly influence VAM development and efficiency. According to Sheikh et al.

(1975), endogonaceous spore population seems to be closely correlated with the level of organic matter content in Pakistani soils. Maximum spore numbers were recovered from soils containing 1-2% organic matter and spores were sparse in soils with below 0.5% organic matter. No such correlation has been observed in temperate soils with higher (2-13%) organic matter contents, although organic manures often enhance mycorrhizal development in tropical soils (Johnson and Michelini, 1974).

An aspect of the study of organic matter that deserves attention is the impact of mycorrhizal root residues themselves on the ecology of VAM fungi in soil. Numerous mycorrhizal plants are annuals and mycorrhizal root systems are thus continuously being incorporated into soils and degraded by soil microorganisms. Almost nothing is known regarding the fate of the endophyte mycelia outside and inside the root tissues.

Redhead (1977) suggested that seasonal dieback of Sudan and Sahel savanna grasses could stimulate endogonaceous spore production, thus increasing spore populations, as observed when arable crops such as maize, barley and wheat are harvested. Mycorrhizal root debris in soil can also be an important reservoir of inoculum. Daft et al. (1980) claimed that most infections of Endymion non-scriptus in nature arose directly from the decaying old root systems through which the new roots grew and Warner and Mosse (1980) indicated some saprophytic ability of VAM fungi in soil that would enable them to establish a base (possibly in particles of organic material) from which they could infect a host plant. Many authors have emphasized that spores are not important for maintaining infection when colonized roots are present especially in the case of natural plant communities when VAM fungi may be non-sporing or poorly sporing types (Sparling and Tinker, 1978). Rives et al. (1980) also suggested that in areas with low annual rainfall, contact between colonized root debris and roots of uninfected plants may constitute the most efficient mode of mycorrhizal spread.

2.5 <u>Biological Interactions with VAM Fungi</u>

In 1904, Hiltner coined the term *rhizosphere* to denote the region of the soil subjected to the influence of plant roots and characterized by intense microbial activity. Many workers have subsequently shown that the microflora of the rhizosphere differs both quantitatively and qualitatively from that in the soil beyond the influence of the root (Parkinson, 1967; Bowen, 1976 and Bagyaraj, *et al.* 972). The rhizosphere effect was greatest with bacteria followed by actinomycetes and fungi. The increased microbial activity in the rhizosphere has been attributed to the extra nutrients available in the region. The extra nutrient supply comes from the root exudates, sloughed-off parts of the root cap, mucigel, root hair residues and abraded epidermal cells (Rovira, 1979 and Tinker, 1980). The microflora of the rhizosphere could influence plant growth in many ways as all plant nutrients pass through this region (Rovira, 1967 and Nye, 1977).

Of the various microorganisms colonizing the rhizosphere, VAM fungi occupy a unique ecological position as they are partly inside and partly outside the host. The internal phase of a mycorrhizal fungus does not encounter competition and antagonism from other soil microorganisms and has an ensured source of nutrients from the host. This advantage enables them to achieve a large and more functional biomass in more intimate contact with the root and thus increases their chances of exerting a greater effect on plants than other microbial species restricted only to the rhizosphere.

Certain generalizations and conclusions about the interactions of VAM fungi with other soil organisms can be drawn. VAM markedly improve nodulation and nitrogen fixation by legume bacteria mainly by providing high phosphorus required for the fixation process. Mycorrhizal plants also allow introduced populations of beneficial soil organisms like *Azotobacter* and phosphate solubilising bacteria to maintain higher numbers than around nonmycorrhizal-plants and to exert synergistic effects on plant growth. In

general, VAM fungi decrease the severity of root diseases. Summary of some important interactions between VAM fungi and beneficial soil organisms are presented in Table 2.2.

Table 2.2 Summary of important interactions between VAM fungi and beneficial soil micro-organisms.

Groups	Species	Interactions
N-fixation bacteria	Rhizobium sp.	Increased VAM infection level, nodulation, N-fixation and plant growth
Free living N-fixation	Azotobacter sp.	Increased VAM infection level,
bacteria	Beijerinkia sp.	VAM spore production and
	Clostridium sp. Azospirillum sp.	bacterial population
Phosphate solubilizing	Pseudomonas sp.	Good bacterial population in
bacteria	Agrobacterium sp.	rhizosphere of mycorrhizal & non-mycorrhizal plants
Phosphate solubilizing	Aspergillus niger	Availability of P increased by
fungi	Penicillum funiculosum	P- solubilizing fungi & uptake increased by VAM

2.6 Production of VAM inoculum

Identification of efficient indigenous strains of VAM fungi along with suitable host and substrate is a pre-requisite for mass production of VAM inocula. Plant growth period of 2-3 months gives a large crop of mycorrhizal spores to produce sizable amount of inoculum. VAM inoculum can also be produced under sterile environment by using hydroponic cultures and transferred organ culture techniques. Although, these techniques have not reached commercialization due to certain limitations.

2.6.1 Inoculation methods:

For successful mycorrhizal infection, the inoculum is placed in the root zone of actively growing plants, which are not heavily fertilized. The quantity of infection by the introduced endophytes depends on placement, inoculum potential, inoculum density, type of inoculum and environmental factors. Various methods proposed for placement of the inoculum are as follows:

Layering or pads:

Inoculum is placed in layers or pads beneath seeds such that the roots penetrating the inoculum will get infected. Presently, it is one of the most effective methods of inoculating plants with VAM fungi. Layering on small and large scale can be done by using manual planters and tractor drawn seeders, respectively.

Banding or side dressing:

In this method, VAM inoculum is placed to sides of seedling or seeds in the zone of root proliferation. Banding mycorrhizal inoculum 5 cm deep and 5 cm away from 2 month old citrus seedling was found to be as effective as placing the inoculum directly on the roots at transplanting and more effective than seed pelleting.

Mixing soil with inoculum:

Mixing mycorrhizal inoculum with soil is the most natural method for inoculating plants. However, it requires large amount of inoculum to obtain rapid infection. Generally, this method is used for inoculating plants in nursery.

Seed pelleting:

In this method, inoculum is extracted from a pot culture by wet sieving and decantation, root retained on 1 mm sieve are fragmented and added to the inoculum. Five ml aqueous solutions (1% w/v) of methyl cellulose and calcium carbonate are mixed with 35 ml of mycorrhizal sievings. This material is poured over seeds (amount depending upon the crop species), mixed thoroughly and seeds are dried.

Pre-inoculation of transplanted seedlings:

In this method, inoculum is placed in the seedbeds and seedlings are transplanted when these get adequately infected. The method is useful with crops like onion and tomato.

2.7 <u>Summary of Literature of Available on VAM Fungi of Important</u> Agroforestry Tree Species of Bundelkhand Region

In literature, a few references on mycorrhizal work on Ber, under nursery conditions are available, whereas no publications could be traced on Chironji, Lasoda and Aonla. Studies conducted on Zizyphus mauritiana raised in pots and inoculated with Glomus fasciculatum, G. mosseae or Scutellospora calospora showed that G. fasciculatum was significantly more efficient than the other two VAM fungi in increasing seedling biomass and uptake of nitrogen, phosphorus, potassium, calcium and magnesium after 98 days of inoculation (Mathur and Vyas, 1996). Guissou et al. (1998) studied the response of Zizyphus mauritiana to inoculation with five species of VAM fungi, Acaulospora spinosa, Glomus mosseae, Glomus intraradices, Glomus aggregatum and Glomus manihotis. This was measured as root colonization, mycorrhizal dependence (MD) and phosphorous concentration in shoot of plants. Root colonization by A. spinosa, G. aggregatum and G. manihotis was high and tree growth increased significantly. G. intraradices also colonized well, but provided little growth benefits. G. mosseae colonized poorly and did not stimulate plant growth. The combination of Z. mauritiana and A. spinosa was the most responsive with respect to total biomass production and phosphorus (P) absorption.

Albizia lebbeck (Desi Siris):

Occurrence of various VAM species has been reported in rhizosphere of A. lebbeck from normal and disturbed sites from various states of India viz. Andhra Pradesh (Srinivas et al., 1999), Uttaranchal (Thapar et al., 1992), coal mine overburden dumps of Madhya Pradesh (Chandra and Jamaluddin, 1999 and Dugaya et al., 1996) and coal, lignite and calcite mine spoil of South India (Ganesan et al., 1991). Habte and Musoko (1994) classified A. lebbeck as highly mycorrhizal dependent species.

Rahangdale *et al.* (1998) studied the efficiency of 12 VAM inoculants for six forest tree species, including *Albizia lebbeck*. A significant increase in plant height, dry biomass and tissue P was observed in VAM inoculated plants. Synergistic interactions have been reported by several workers (Suvarna *et al.*, 2002; Raizada *et al.*, 1998 and Pokhriyal *et al.*, 1992) between AM fungi and *Rhizobium*, in *A. lebbek*.

Kumar et al. (1999) reported that Carbendazim inhibited VAM root colonization in Sesbania grandiflora and A. lebbeck, where as Quinalphos and 2,4-D enhanced percentage of infection and number of mycorrhizal propagules in both species. Udaiyan et al., (1996) reported that seedlings in Formaldehyde fumigated beds had stunted growth and were chlorotic, had poor VAM root colonization and spore density. Total biomass and field survival rates of the seedlings were very low. In contrast, seedlings from Fytolan drenched beds showed normal growth, enhanced biomass and a higher field survival rate, intense VAM root colonization and higher spore density.

Azadirachta indica (Neem):

Different VAM species have been reported in rhizosphere soil of neem (Azadirachta indica) from different states of India. Bala et al. (1989) reported more than 50% root colonization. Glomus and Gigaspora were common VAM genera and roots were associated with VAM infection up to 250 cm depth. Mohan et al. (1995) studied root and rhizosphere soil samples of neem from various Forest Department nurseries and plantations in Rajasthan. They reported that mean number of VAM fungal propagules and percentage root infection of plants were greater in plantation samples than in nursery samples. Glomus species was dominant in nurseries (5 species) and plantations (9 species). Sclerocystis species was also common in plantations. Among the Glomus species, G. fasciculatum was predominant in nurseries and plantations. Pande et al. (1999) reported three VAM genera from rhizosphere soil of neem viz., Glomus (80%), Gigaspora (16%) and Acaulospora (4%). Mohan (2000) recorded the presence of Glomus fasciculatum, G. aggregatum

and G. microcarpum from rhizosphere of Acacia nilotica, A. tortilis, Azadirachta indica, Prosopis cineraria, P. juliflora and Tecomolla undulata in nurseries and plantations in different location of Rajasthan. Mehrotra, et al. (2000) studied the composition of VAM fungi in the rhizosphere of poly-pot raised seedlings of Acacia nilotica, A catechu, A. mangium, A. auriculiformis, A. tortilis, Dalbergia sissoo, Azadirachta indica, Michelia champaca, Pterigota alata, Tecomolla undulata, Paulownia fortunoi and P. tomentosa. The seedlings were procured from forest nurseries in Uttar Pradesh, Haryana, West Bengal and Rajasthan. In all tree species except for Michelia champaca and Pterigota alata, Glomus predominated, followed by Acaulospora. Gigasporaceous fungi (Gigaspora and Scutellospora) were present in some Acacia species from most of the locations and in D. sissoo from some of the locations. Gigaspora was present in insignificant numbers in Azadirachta indica.

Beneficial effect of inoculations with different species of VAM fungi on neem seedlings have been reported by some workers. Phavaphur *et al.* (1996) studied the growth and nutrient uptake of neem seedlings in response to inoculation with the *Glomus intraradices* at two levels of phosphorus (0.65 and 1.30 mMP). Growth of VAM plants was similar at both P levels, while the growth of non-colonized (non VAM) plants increased with increasing P supply. At the low P level, VAM plant had greater leaf area, shoot, root and leaf dry weight and a greater root: shoot ratio than non-VAM plants. The study showed that VAM inoculations were beneficial for growth enhancement and nutrient uptake under low phosphorus conditions. Sumana and Bagyaraj (1999) showed that among nine VAM fungi tested, neem seedlings responded best to inoculation with *Glomus mosseae* followed by *G. fasciculatum* with regards to plant height, stem girth, bio-mass, phosphorus content, zinc concentration, bio-volume index, mycorrhizal root colonization and spore number in the root zone soil.

In literature, some reports on effect of management practices on colonization of neem plants are available. Srinivasan *et al.* (1996) reported that effluent irrigation significantly increased the root infection and spore numbers of VAM species in *Azadirachta indica*. Pande *et al.* (2002) screened different strain of VAM fungi for their tolerance to varying level of P, salinity and soil moisture while infecting neem. *Glomus mosseae* was found to be the more saline-resistant species as compared to *Glomus fasciculatum*, *Gigaspora margarita* and mixed inocula. The maximum infection was observed when soil was maintained at 30-60% of available water in plants inoculated by different VAM species. *Glomus fasciculatum* sporulated the most, stimulated the highest biomass production and was recommended for propagation of neem seedlings in the nursery.

Kalavathi and her co-workers (2000) have reported the synergistic effect of inoculations with VAM fungus (Glomus fasciculatum) and phosphorus solubilizing bacteria (Pseudomonas striata or Bacillus polymyxa) on growth and nutrient uptake of neem seedlings.

Dalbergia sissoo (Shisham):

Occurrence of various VAM species have been reported in rhizosphere soil of Dalbergia species from different part of India, under divergent conditions. Jamaluddin et al. (2001) reported that Glomus was dominant species with different trees including Dalbergia sissoo, in a sludge garden of Ballarpur Paper Mill, Maharastra. Reported species included Glomus deserticola, G. leptotichum, G. intraradices, G. mosseae, G. aggregatum and G. invermaium. Mehrotra et al. (2000) conducted study to determine the composition of VAM fungi in rhizosphere of poly-pot raised seedlings of some forest trees. Glomus predominated, followed by Acaulospora and Gigasporaceous fungi. Gurumurthy and Sreenivasa (2000) reported two predominant VAM spore types in rhizosphere soil of tamarind, shisham and casuarinas from different location (Dharwad, Prabhunagar and Sirsi) in Northern Karnataka. Thapar et al. (1992) reported presence of VAM fungi

from root samples of one year old *Dalbergia sissoo* seedlings, collected from nursery stocks at New Forest, Dehradun, Uttaranchal. Thapar *et al.* (1991) reported presence of 13 *Glomus* species, 1 *Scutellospora* and 2 *Sclerocystis* from three districts of Haryana (Kurukshetra, Hissar and Rohtak) from rhizosphere of *Prosopis juliflora*, *Acacia nilotica*, *Dalbergia sissoo* and *Eucalyptus tereticornis* growing in sodic soil.

Many studies on mycorrihzal development and tree growth at disturbed sites like, coal mine overburden dumps (Chandra *et al.*, 1999), copper, aluminum and coal mines (Bisen *et al.*, 1996), sodic and alkaline soils (Thapar *et al.*, 1990), degraded bhata land (Verma *et al.*, 1999), sludge dumps of paper mills (Jamuluddin *et al.*, 2001) etc. have been conducted in different parts of our country. In such experiments, data on population status of VAM fungi in rehabilitated mined sites is compared with the populations under natural vegetation and barren mine spoils. Poor spore counts have been reported on barren mine spoils, whereas reasonable number have been reported with most of rehabilitated sites. In some of these studies, percentage infections of VAM fungi have been correlated with above ground biomass of the trees and it has been suggested that application of specific strains of VAM will increase the tree growth (Dugaya *et al.*, 1996).

Effect of cropping system: Rajashekhara et al. (1989) studied the effect of cropping system on VAM development in red-gram and sunflower. They have reported that colonization and sporulation of VAM fungi increased with decreasing distance from the trees (Dalbergia sissoo, Dendrocalamus strictus, Tectona grandis, Leucaena leucocephala and Casuarina equisetifolia). L. leucocephala supported the highest mycorrhizal development in both crops.

Effect of seed source on VAM colonization: Devagiri et al. (2001) studied seed source dependent variation in mycorrhizal colonization in Dalbergia sissoo. Twenty nine seed sources from India and Nepal were screened to identify good mycorrhizas forming seed sources. Results indicated good

amount of variation among different seed sources with respect to VAM colonization index (24 to 54%).

Interactions with other microbes: Paroha et al. (2000) reported synergistic interactions between VAM and Azotobacter inoculation on growth and biomass production in four forestry species, including Dalbergia sissoo. Kaushik et al. (2003) studied interactions between VAM fungi, phosphorus fertilizer and water stress application on nodulation in Acacia nilotica and Dalbergia sissoo. Application of Glomus mosseae, P fertilizer and water significantly increased nodule formation in both tree species. Water stress conditions significantly reduced nodule number and size in A. nilotica but did not have significant difference in D. sissoo. Kaushik et al. (2000) studied the impact of Glomus mosseae inoculation on root pathogens in Acacia nilotica and Dalbergia sissoo. Results indicated that previously VAM inoculated plants significantly increased survival percentage of their hosts against Rhizoctonia solani and Fusarium oxysporum.

Effect of fungicides on VAM: Two important reports are available in literature on effect of fungicides on colonization and development of VAM in Dalbergia species. All three fungicides tested by Jamaluddin et al. (1998) namely, Dithane M-45 (Mancozeb), Bavistin (Carbendazim) and Captafol enhanced infection by VAM and spore formation in the rhizosphere at 0.1% concentration. At 0.2% the fungicides suppressed VAM colonization. Seedlings growth also increased with 0.1% fungicidal treatment. In another study, Udaiyan et al. (1996) studied the effect of Formaldehyde fumigation and Fytolan drench on VAM fungi and nodulation in 12 leguminous forest seedlings, including Dalbergia latifolia. Seedlings in the Formaldehyde fumigated beds had stunted growth and were chlorotic, had poor VAM root colonization (18-25.3%), spore density (3.1-10.6/ g soil), lower nodule numbers (3-8 per plant) and nodular biomass (100-870 mg/ plant). Total biomass and field survival rate of the seedlings were very low. In contrast, seedlings from Fytolan drench beds showed normal growth, enhanced

biomass, a higher field survival rate, intense VAM root colonization and higher spore density, higher nodular number and nodular biomass than control seedlings.

Selection of efficient VAM fungi: Many reports on selection of efficient VAM fungi for seedlings of Dalbergia sissoo and D. latifolia are available. The results showed that inoculated plants had greater plant height, stem girth, dry weight and P content than non-inoculated plants. They also had greater mycorrhizal root colonization and higher spore numbers in rhizosphere soil. For Dalbergia sissoo, Sumana et al. (1993) reported best results with Glomus fasciculatum followed by Gigaspora margarita. Gurumurthy et al. (1999) got best results with G. fasciculatum under unsterile and sandy clay soil. Sumana and Bagyaraj (1998) obtained best result with Glomus leptotichum and G. fasciculatum in case of Dalbergia latifolia.

Leucaena leucocephala (Subabool): In literature, several references are available in which increase in juvenile growth of Leucaena seedling have been reported by inoculation with various VAM fungi viz., Glomus fasciculatum (Mukerji et al., 1996; Puthur et al.,1998 and Koffa et al.,1995), G. macrocarpum (Puthur et al.,1998), G. etunicatum (Koffa et al.,1995 and Dixon et al., 1994), G. deserticola (Dixon et al., 1994 and Atayese et al.,1993), G. intraradices (Dixon et al., 1994) and Gigaspora margarita (Koffa et al.,1995 and Dixon et al., 1994) under divergent conditions. Dixon et al. (1994) have reported that VAM inoculated seedlings of Leucaena maintained slightly greater leaf water potential, leaf stomatal conductance and photosynthesis relative to the non- mycorrhizal plants at the peak of the drought treatment and after re-watering. The data suggest that VAM fungi help Leucaena leucocephala to avoid drought stress.

Kumar et al. (2000) investigated mycorrhizal dependency (MD) of 29 agro-forestry tree species representing 14 families. Species were divided into three groups: Those with high mycorrhizal dependency (Azadirachta indica, Leucaena leucocephala, Gliricidia maculata, Sesbania grandiflora, Cassia

siamea and Acacia melanoxylon), those with moderate MD (the majority), and those with no MD (Diospyros melanoxylon, Mangifera indica, Murraya koenigii, Polyalthia longifolia, Psidium guajava, Saraca indica and Zizyphus mauritiana). No correlation was observed between percentage mycorrhizal infection and MD. Manjunath and Habte (1991) suggested that species that are marginally dependent on VAM fungi (Sesbania pachycarpa) tend to have lower P utilization efficiency, higher P absorption rate and higher growth rates compared with moderately (Leucaena retusa and S. grandiflora) or highly (Leucaena leucocephala) VAM dependent species when they are not colonized by mycorrhizal fungi. It was also suggested that species differing in growth rates could differ in their mycorrhizal dependency even when they have similar root morphological characteristics. Habte and Manjunath (1991) showed that species differing in their mycorrhizal dependency differed with respect to the soil solution P concentration required for the expression of maximum VAM effectiveness, the degree to which increasing concentration of P depressed VAM infection and the pattern of immobile nutrient accumulation. Manjunath (1990) showed that highly dependent plant species have lower growth rate, low P uptake rate and higher P utilization efficiency than marginally dependent species under mycorrhizal conditions. The results illustrated that soil solution P levels could serve as a basis for categorizing plant species into distinct MD groups. Among plant characteristics studied, root morphological characters were observed to be the most important determinants of MD.

Bansal et al. (1998) showed the mycorrhizal fine root litter of L. leucocephala worked as an effective bio-fertilizer, contributing to a several fold increase in the growth of Zea mays. Root litter with VAM inoculation had no additional effect. Harinikumar and Bagyaraj (1995) studied the active spread of Glomus fasciculatum hyphae from the roots of inoculated plants through soil was studied using rectangular battery boxes partitioned into 3 compartments, planted with mycorrhizal L. leucocephala, non-mycorrhizal L.

leucocephala and an unplanted one in the middle, filled with soil. Care was taken to prevent root growth from one compartment to the other. The results showed that mycorrhizal hyphae grew to a distance of 300 mm in 180 days. The un-inoculated plants became mycorrhizal after 180 days, confirming the active spread. Bansal and Mukerii (1994) showed that the presence of specific mycoflora in the rhizosphere of mycorrhizal roots was mediated through root exudates rather then being an outcome of improved P nutrition. Soedarjo and Habte (1993) concluded that organic matter, in appropriate amounts, could protect sensitive plants and VAM symbiosis against Al toxicity in acid soils. Maximum mycorrhizal inoculation effects are not likely to be attained unless the soils are also amended with Ca. Helal et al. (1998) reported increased Zn and Cu uptake by VAM inoculation in Leucaena leucocephala. Habte and Aziz (1991) concluded that extent of mycorrhizal colonization of Leucaena leucocephala increased when lost nutrient are replaced in highly eroded soils. P was the most important nutrient limiting mycorrhizal effectiveness, followed by N and lime. Soil amended with Mo at 4.4 kg/ ha increased mycorrhizal colonization of Leucaena leucocephala in eroded soils. However, P content was not affected by its application (Aziz and Habte, 1988). Organic residue (dried leaves and twigs of Leucaena) amendments at 7.38% decreased mycorrhizal colonization of Leucaena leucocephala by Glomus aggregatum (Aziz and Habte, 1988). Possible toxic effects of Mn on mycorrhizal symbiosis are briefly discussed. Aziz and Habte (1989) studied the effect of inorganic N on development of mycorrhizal symbiosis in Leucaena leucocephala in eroded soils. The extent of VAM colonization and P content of Leucaena sub leaflet increased in eroded soils at 25 ppm N. A further increase in N level did not improve above mentioned parameters. Maluf et al. (1988) reported that Al- intolerant cultivars of Leucaena leucocephala benefited more from the mycorrhiza than Al-tolerant one. The higher relative increment of shoot nutrients occurred in the Al-intolerant cultivars when colonization by G. leptotichum and native VAM fungi.

VAM vls P: Bagyaraj and Machado (1996) studied VAM activity in Leucaena at .007, .022, 0.04, 0.088 and 0.232 mg P/ litre soil solution and found it to be maximum at .022mg P/ liter. Costa et al. (1992) reported the possibility to reduce the level of P fertilizer of VAM inoculation in P deficient soils. Costa et al. (1992) reported that VAM inoculation increased dry matter yield at 0, 20, 40, 60 and 80 kg/ ha P₂0₅ Highest level of VAM colonization was observed at 40 kg/ ha P₂0₅. Manjunath and Habte (1992) studied the effect of inoculation of Leucaena leucocephala with Glomus aggregatum at soil solution P levels between 0.003 and 0.6mg/ litre DM yield was increased at all P levels. Costa and Paulino (1990) studied the effects of inoculation of Leucaena leucocephala with VAM fungi (Glomus etunicatum, Acaulospora muricata, Gigaspora margarita and Scutellospora heterogama) with and without added P (at 22 kg/ha). Increase in dry matter yield, P and N content, VAM infection and nodulation was reported under both conditions. Manjunath and Habte (1989) reported that VAM inoculated Subabool plants were very efficient in P absorption and accumulation, but they were not superior to non-VAM plants in P utilization. Manjunath et al. (1980) studied the response of Leucaena leucocephala to VAM colonization and rock phosphate fertilization. They reported that plants associated with VAM fungi effectively utilized P from rock phosphate.

Microbial Interaction: Many workers have reported synergistic interaction of VAM with Rhizobium in Leucaena (Pahwa 1995; Cao et al., 1995 and Dixon et al., 1993). Some reports on enhancement of root colonization of legumes by arbuscular mycorrhizal fungi through the inoculation of the legume seed with commercial yeast (Sacchromyces cerevisiae) are also available in literature (Singh et al., 1991 and Singh and Kapoor, 1989).

Pesticide: Reports on effect of some fungicides (Formaldehyde, Fytolan, Thiram and Chlorothalonil) and one nematicide (Fenamiphos) on VAM fungi and growth of *Leucaena leucocephala* seedlings are available in literature. Habte and Manjunath (1992) studied the effect of Thiram on VAM symbiosis

in Leucanea leucocephala. They reported that mycorrhizal colonization of host roots was low and did not change, as the concentration of Thiram increased from 0 to 1000 mg/ kg in un-inoculated soil. In inoculated soil, colonization was high which decreased with increasing Thiram concentration. Symbiotic effectiveness was reduced and completely eliminated with increasing Thiram concentration. If, Thiram levels did not exceed 125 mg/kg, addition of P to soil compensated for Thiram induced loss of VAM activity. Chlorothalonil reduced mycorrhizal colonization of roots, shoot P concentration and uptake and dry matter yields at all tested concentrations (Aziz et al., 1991). Results of another study showed that toxic effect of chlorothalonil declined as a function of time. A significant level of toxicity persisted 12.5 weeks after application of the chemical to soil. Habte and Manjunath (1988) concluded that Fenamiphos, a nematicide is not likely to influence the growth of Leucaena or its symbiotic association with VAM fungi, if the concentrations applied does not exceed levels known to suppress nematodes.

Effect of VAM on drought tolerance: Osonubi et al. (1991) concluded that the drought response index may be a useful determinant of mycorrhizal dependency, as they are inversely related. Michelsen and Rosendahl (1990) demonstrated the potential of VAM inoculated plants of L. leucocephala and A. nilotica in reforestation programmes in degraded area of arid tropics, particularly to counter drought stress following transplantation.

Effect of VAM on enzyme activity phosphatase: Jagpal et al. (1991) reported that phosphatase activity (used to assess uptake of phosphorus) was greater in Glomus macrocarpum inoculated Leucaena leucocephala plants.

Effect of simulated erosion of VAM: Aziz and Habte (1989) studied the sensitivity of three vesicular arbuscular mycorrhizal species to simulated erosion using Leucaena leucocephala as an indicator host. The extent of colonization of Leucaena roots increased significantly due to VAM inoculation of the eroded and un-eroded soils. The highest level of VAM

colonization was observed when Leucaena leucocephala was grown in association with Glomus aggregatum, followed by G. mosseae and G. etunicatum. Increased infection associated with inoculation of the eroded soil did not result in enhanced mycorrhizal effectiveness. Inoculation of the uneroded soil, however, led to significant improvement in root colonization as well as in symbiotic effectiveness. Suppression of mycorrhizal effectiveness in the eroded soil appears to be a result of nutrient deficiency. The results showed the importance of restoring lost nutrients before differences in VAM species could be effectively exploited for successful establishment of mycorrhizal plants in eroded soils.

Habte et al. (1988) concluded that development of VAM effectiveness is the phase of the VAM symbiosis that is the most adversely influenced by simulated erosion and that this effect appears to be caused primarily by insufficient P in the soil solution.

VAM v/s soil type: Habte and Fox (1989) evaluated symbiotic effectiveness of Glomus aggregatum in five widely differing tropical soils. The soils differed in the time required for expression of initial and maximum VAM effectiveness. The ratio of the area enclosed by the effectiveness curve of G. aggregatum to that enclosed by the effectiveness curve of a test soil was a good indicator of the response of L. leucocephala to soil inoculation with G. aggregatum.

In *Jatropha* and *Pongamia*, a very few references are available. Adholeya and Reena (2006) have reported that mycorrhizal inoculations speed up flowering and fruiting in *Jatropha curcas* and 30% increase in bio-mass was reported. Rahangdale *et al.* (1998) have reported that VAM inoculation significantly increases plant height, dry biomass and tissue phosphate in *Pongamia pinnata*.

Materials And And Methods

MATERIALS AND METHODS

3.1 <u>Description of Sites/ Fields</u>

The study was conducted at National Research Centre For Agroforestry, Jhansi (25°27' N latitude, 78°35' E longitude and at about 271 m above msl). On agro-ecological zone map of India, Jhansi lies in the hot semi-arid zone. Three distinct seasons are recognized in a year. Summer (March-Mid June) is hot and dry, rainy season (Mid June- September) is warm wet and winter (October- February) is cool dry. The area receives annual rainfall between 700-1150 mm mostly during monsoon period (Mid June- September). The mean maximum temperature varies from 23°C (January) to 42°C (May). Correspondingly mean minimum temperature varies from 5°C (January) to 26°C (May). Meteorological data of NRCAF, Jhansi during experimental period is presented in Appendix I.

The main soil types at the experimental fields were red and black. Red soils occurred at elevated spots in the field. These were shallow, gravelly, light textured, pH varied from 6.08 to 6.70 and organic carbon varied from 0.38% to 0.65%. Black soils were situated in comparatively low lying areas and were fine textured, highly water retentive, pH varied from 5.70 to 6.78 and organic carbon varied from 0.41% to 0.67%.

A total of 96 plants were selected, which consisted of 48 Aonla (*Emblica officinalis* Gaertn.), 28 Ber (*Zizyphus mauritiana* Lamk.), 12 Lasoda (*Cordia myxa* Roxb.) and 8 Chironji (*Buchanania lanzan* Spr.) plants. The selected trees were from six sites viz., National Research Centre For Agroforestry, Jhansi campus (NRC), Nagar Palika Baruasagar, district Jhansi (NPB), village Katili, Jhansi (VKJ), village Nareta, Datia (VND), village Jakhlon, Lalitpur (VJL) and Nilkanthh, Pauli (NP) (Fig. 3.1). Among Aonla plants, 40 were from NRC and four each from NPB and VKJ. Aonla plants at NRC were selected from four different fields such that these covered three

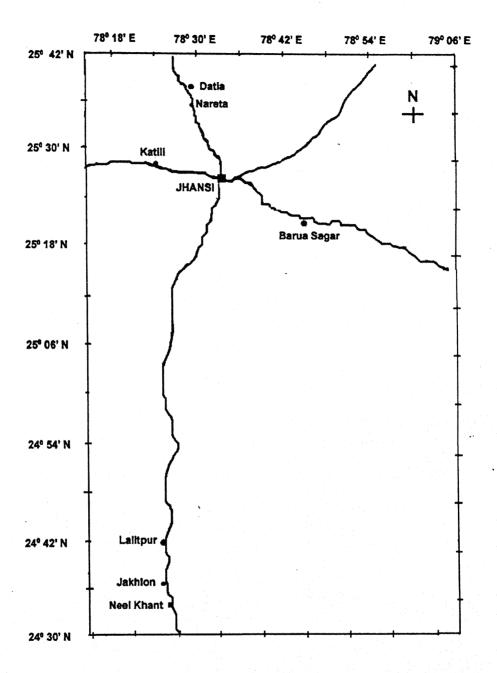


Fig. 3.1 Location of diffrent sites from where root / soil samples were collected from rhizosphere of selected minor fruits.

varieties of the fruit crop (Kanchan, Krishna and Chakaiya), three soil types (red, black and lateritic) and upland/ lowland plants. Marked plants of Aonla from NPB and VKJ were from a single field, at respective sites. All selected Ber plants were from NRC and covered its different varieties/ strains viz., Banarasi Karaka, Gola, Seo, Desi, Makor, Ghot and Jhar-beri. Eight plants of Lasoda were selected from NRC, four from block plantation and four from silvipasture system. Four plants of Lasoda were selected from a village Nareta in Datia district of MP. Among Chironji plants, four were from a village Jhakhlon in Lalitpur district and other four were from Nilkanthh, Pauli (MP). (Table 3.1).

Table 3.1 Description of sites/ fields

Fruit tree	Site	Number of plants	Remarks
Aonla	NRCAF	40	Cover 3 varieties, 3 soil types, uplad and lowland plants
	Katili	04	Desi plants and red soil
	Baruasagar	04	Desi plants, red soil and
			Irrigated
Ber	NRCAF	28	Cover 7 varieties/
			Wild relatives
Chironji	Jhakhlon	04	Dry and un-cultivated land
<u>.</u>	Nilkanthh	04	Spring water
Lasoda	NRCAF	08	4 silvi-pasture and
			4 block plantation
	Nareta	04	Black fertile soil

3.2 Sampling

Root and rhizosphere soil samples of Aonla, Ber, Chironji and Lasoda were collected from selected sites/ fields during July 2003 - June 2005. Reasonable care was taken while taking root samples such that it contained sufficient terminal feeder roots. To obtain representative samples of entire root system, roots were taken from four or five different portions of the root system and combined. The samples were either processed immediately after sampling

or preserved in standard formalin-aceto-alcohol (FAA) solution. FAA was prepared with 50% alcohol with V/V/V ratio of 90:5:5.

3.3 Clearing and Staining Root Specimens

3.3.1 Reagents:

10% Potassium hydroxide solution

• Alkaline H₂O₂

25% Ammonium solution: 3 ml

10% H₂O₂

: 30 ml

Distilled water

: 567 ml

• 1% HCl

Lactoglycerol

Lactic acid

: 876 ml

Glycerine

: 64 ml

Distilled water

: 60 ml

• Staining solution

0.01% Acid fuschin

: 0.01 g acid fuschin in 100 ml lactoglycerol

0.05% Trypan blue

: 0.05 g trypan blue in 100 ml lactoglycerol

3.3.2 Procedure: Clearing and staining of root specimens was done following the method of Phillip and Hayman (1970). Root samples, collected from field were washed under running tap water thoroughly, placed in glass vials containing 10% KOH solution and heated at 90° C for about 1 hour. The KOH solution clears the host cytoplasm and nuclei and readily allows stain penetration. After heating, KOH solution was poured off and the root samples were washed using at least three complete changes of tap water or until no brown colour appeared in the rinse water. Washed roots were placed in alkaline H_2O_2 at room temperature for 1 hour or until roots were bleached. Then the roots were washed with tap water thoroughly using three changes. The alkaline H_2O_2 solution was made as per need as it loses its effectiveness on storage. After H_2O_2 treatment, the samples were treated with 1.0% HCl for

30 minutes and then the solution was poured off. The roots were not rinsed with water after this step because these must remain acidified for proper staining. The root samples were kept in 0.01% staining solution (acid fuschin) after HCl treatment and kept at 90°C for 1 hour. After removing fuschin solution the root specimens were placed in de-staining solution for mycorrhizal assay. The specimens were not washed with water after staining because the stain is readily removed from the fungal structures. The destaining solution was the standard staining solution as mentioned above, without the stain.

3.4 Mycorrhizal Assay

Mycorrhizal colonization percentage was determined by grid line intersection method of Giovannetti and Mosse (1980). Root segments, each approximately 1 cm long, were selected at random from stained samples and mounted on microscopic slides in groups of 10. Twenty root segments from each sample were used for assessing length of cortical colonization in millimeters, at 100 X. Average of the readings from a sample, were expressed as percentage of root length colonization.

3.5 Separating Spores from Soil

Spores were isolated from soil according to the method of Gerdemann and Nicolson (1963) and counted (Gaur and Adholeya, 1994). Depending upon spore numbers and soil texture, 50-100 g soil samples were weighed. This allowed spore number to be expressed relative to soil weight. Generally less than 100 g of soil was best, but larger samples were used if spore population in soil was low. Vigorous washing was avoided. Soil was mixed in a substantial volume of water and decanted through a series of sieves. Roots and coarse debris was collected on a coarse sieve, while spores were captured on one or more fine sieves. Sievings were then collected in jars. For observation under stereo-microscope, the sievings were transferred onto the

grided petri dishes (11cm). Number of spores were counted and expressed as spores per unit of the soil sample.

3.6 Preparation of Diagnostic Slides

3.6.1 Reagents:

Polyvinyl alcohol-lactoglycerol (PVLG) mountant

Polyvinyl alcohol

: 8.30 g

Distilled water

: 50 ml

Lactic acid

: 50 ml

Glycerine

: 5 ml

Meltzer's reagent-Mixed 1:1 (v/v) with PVLG

: 5 mi

Chloral hydrate

:100 g

Distilled water

:100 ml

Iodine

: 1.5 g

Potassium iodide

:5g

were prepared by using the methods of Schenck and Perez (19). Clean spores were picked up with a pipette and placed in a watch glass with distlled water. A drop of mountant was placed on left and right side of a clean and dry microscope slide, allowing space on one end for a label. The spores were added with minimum amount of water to the mountant. The spores and mountant were mixed gently with a needle to disperse the spores. The mountant was allowed to set for 3-5 minutes, which became more viscous before adding a cover slip. During this time, spores were positioned in the center of the drop with proper orientation, so that the desired features were visible. A clean and dry cover slip was moved at 45° angle toward the mountant. After contact, few seconds were allowed for the mountant to spread along the cover slip surface. The cover slip was released gently, onto the mountant. This minimized formation of air bubbles. No pressure was applied to the cover slip. The relevant steps were repeated with the second drop of

mountant. Applying little pressure on the cover slip with an eraser or with your thumb broke spore wall of mycorrhizal spores, under one cover slip. Mountant with spores was dried for several hours or overnight in a flat position. After this period, broken spores were examined. It is important that the break of the walls should be adequate. Excess mountant was cleaned with a cotton swab moistened with a solvent such as ethanol. Edges of the cover slip were sealed with clear fingernail polish or other sealant and the sealant was allowed to dry. The observations were made as listed on the INVAM Worksheet (Appendix II) and additional slides were made, if the condition of the spores on the first slide was not adequate for a detailed examination.

3.7 <u>Identification of VAM Genera</u>

There are only six genera of fungi that contain species, which are known to produce arbuscular mycorrhizae with plants. Two of these genera, Glomus and Sclerocystis, produce only chlamydospores. Four genera from spores that are similar to zygospores (referred as azygospores in further and Scutellospora, Acaulospora Gigaspora, namely, descriptions) Entrophospora. The genera are distinguished by their spore characteristics and the relationship of the spore to the associated hyphal attachments. The existent genera were established to reflect the manner in which the spores were produced, except for the genus Scutellospora. Species in this genus are distinguished from species in the closely allied genus Gigaspora by wall characteristics, method of germ tube formation, and auxiliary cell characteristics. VAM fungal spores from rhizosphere soil of various tree species were identified following the keys of Trappe et al. (1982) and Schenck and Perez (1987).

1a	Spores produced as chlamydospores
1b	Spores not produced as chlamydospores
	2a Sporocarps only with spores radiating from a central core of hyphae
	2b Spores formed singly in soil or in sporocarps; if in sporocarps, spores not
	radiating from a central core of hyphae
3a	Azygospores formed near or below a swollen hyphal terminus
3b	Azygospores formed on a swollen hyphal terminus
	4a Spore formed laterally on hypha, below a swollen hyphal terminus
	4b Spore formed within the hypha, below a swollen hyphal terminus
	Entrophospora
5a	Spore with 2 or more wall groups, the inner containing a coriaceous or
	membranous wall
5b	Spore of only 1 wall group, auxiliary cells echinulate or finely papillate
20	
	_ ******* *****

Many observations required for the separation of genera were made with a stereo-microscope. Spores were viewed in water in reflected/transmitted light to observe hyphal attachments. Spores were rolled or turned so that attachments were not obscured. Spores placed in PVL or PVLG (viscous mountants) were properly oriented.

3.8 Trap Culture/ Inoculum Production

Rhizosphere soil collected from selected plants of Aonla, Ber, Chironji and Lasoda was used for inoculum production. It was mixed in 1:1 ratio (v/v) with autoclaved coarse sand. The mixture was transferred to 15 cm plastic pots, which were seeded with maize and black-gram. The cultures were grown in a greenhouse for at least four months. Some sporulation occurred during first three months, but it was during the fourth month when plant shoots (and

roots) had ceased growth and carbon seemed to be repartitioned to sporulation rather than mycorrhizal development. A longer time was avoided because other fungi, which often contaminate the cultures. Fertilization was kept to a minimum, being applied only when plants showed signs of phosphorus deficiencies (purpling of leaf sheaths) or nitrogen deficiency (chlorosis of young leaves). Pots were left to dry undisturbed in a shaded room with a fairly stable temperature so that the drying period was not too rapid (1-2 weeks). For trap cultures that were propagated for 1-2 additional cycles, the bagged material was used as inoculum (undiluted) within 30 days of harvest. If sporulation was extremely low, then the pots were not harvested, but shoots removed and the pot contents reseeded.

3.9 Establishment Monospecific Cultures

- 3.9.1 Spore collection: Spores were extracted by wet sieving and decantation method from the pot culture material 2-3 days before inoculation onto plant seedlings. After repeated washing, the spores of each target species were collected manually and stored in a watchglass (sealed in petri dish) at 4°C. Spores were examined daily until the day of inoculation and any with changed morphology (loss of contents, collapse and color change) or suggestion of parasitism were removed. Before inoculation, water was added to the spore preparation, the watch glass agitated and any particles, hyphal fragments or atypical spores were removed. Cone-trainers (presterilized in 10% bleach) were first filled to the top with sterile sand-soil mix, labels applied and 6-7 cm deep holes were made in centers with a sterile glass rod. An alcohol lamp and a beaker of 95% ethanol are set up for flaming the glass rod after each transplant operation.
- 3.9.2 Seedling preparation: Approximately 12 days before a monospecific culture was planned on being set up, approximately 40-50 sorghum seeds were evenly spaced in a 15-cm diameter pot using our standard sand-soil mix. This seedling rate provides enough seedlings for a given "run", and they were far

enough apart to separate without much damage to root systems. Sorghum was used because it has a hardier root system that buffered the seedling against transplant shock. By 12 days, pot contents were removed intact. This mass was placed in a large glass bowl filled with water so that it was completely immersed. Roots were gently teased from the growth medium and from each other and then left undisturbed for at least 30 minutes.

3.9.3 Inoculation: Three seedlings were gently collected, spores (in 200 µl water) were pipetted along the length of the intertwined roots, so they were in contact with the maximum range of root physiological states. Spores adhere naturally while excess water drips from root tips. Seedlings were immediately transplanted into the center hole of a cone-trainer. The glass rod was used to refill hole and compact soil around seedlings until they stand upright. Care was taken to distribute roots along length of the hole. Cone-trainers were topped off with sterile growth medium all cone-trainers were watered gently and placed in a room with indirect lighting for 24 hours and then moved to greenhouse. Cone-trainers are not fertilized for at least 14 days after transplantation to optimize initial mycorrhizal development.

3.10 Mass Culture

Isolated spores were surface sterilized and subjected to mass culturing, for which, sterilized sand was filled in 1.8 kg capacity plastic pots. The pots were inoculated @ 900 spores/ pots (300 spores/ seed site, 3 sites per pot). Sterilized maize seeds germinated on towel paper were placed right above the VAM inoculum. Pots were watered on alternate days with de-ionized water and ¼ strength Hoagland's (Appendix III) solution was supplied at weekly intervals. The pots were subjected to 3 cycles of plant growth, as described for trap culturing. This gave a ready to use homogenous inoculum of indigenous VAM fungi.

3.11 Most Probable Number (MPN) Method

Prior to use of the inoculum, a serial dilution technique was applied to ascertain the number of infectious propagules (Porter, 1979) as follows:

- 1. 350 g sterile soil + 50 gm of soil from layer (ii) of the inoculum pots
- 2. 85 g of soil from step (1) + 255 g of sterilized soil (dilution I)
- 3. 85 g of soil from step (2) + 255 g of sterilized soil (dilution II)
- 4. 85 g of soil from step (3) + 255 g of sterilized soil (dilution III)
- 5. 85 g of soil from step (4) + 255 g of sterilized soil (dilution IV)
- 6. 85 g of soil from step (5) + 255 g of sterilized soil (dilution V)

Aliquots (50 gm) of substrates containing various levels of the inoculum were placed in plastic pots (height 9.5 cm, diameter 9.5 cm), filled with 150 gm of sterilized soil. Maize seeds were sown and layered with sterilized soil. Five replications of each dilution were maintained. Harvesting was done after 6 weeks by carefully cutting the pots and critically recognizing the layers. Only the roots from the IInd layer (fig. 3.2) were stained according to Phillips and Hayman (1970) as follows:

Fine roots were heated with 10% KOH for 45 min., washed with water, placed in 2% HCl for 5 minutes and stained with 1.0% trypan blue in glycerol for 24 hours, de-stained in 50% glycerol-water (v/v) for 12 hours. Subsequently the roots were observed for infection, designated by + or - for infected or non-infected roots respectively.

MPN was calculated using the formula:-

$$Log \Omega = x log a - k$$

Where Ω = number of infectious propagules,

x = mean number of cups with infection i.e. <math>x = total number of infected cups/ number of replications/ dilution

a = dilution factor

In order to define the value of 'k', the values of x & y are required where

y = s - x and

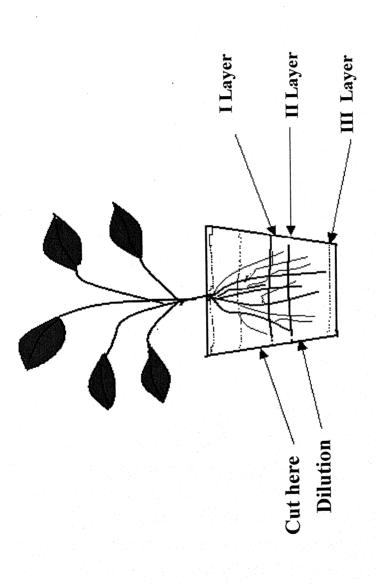


Figure 3.2 A schematic diagram showing the manner of using root fragments for MPN

S = number of dilution level

'k' value is then determined from Table VIII of Fisher and Yates (1963) for the given values of 'x' & 'y' (Appendix IV).

3.12 Polyhouse Experiments

- **3.12.1 Screening for Efficient VAM Species:** The effect of inoculation of seven VAM species, six belonging to *Glomus* and one *Acaulospora*, on the growth and development of Aonla, Ber, Chironji and Lasoda was studied. The inoculum was used from the purified cultures.
- **3.12.2 Substrate sterilization:** Red soil was used as potting mixture, soil was passed through 2 mm sieve, moistened and filled in cotton begs which were autoclaved for 8 hours at 121°C and 15 psi. On the following day, the begs were opened and the soil spread out for the whole day only to be rebegged and autoclaved subsequently.
- **3.12.3 Seed sterilization:** Seeds of Aonla, Ber, Chironji and Lasoda were scaricified and surface sterilized with 0.1% mercuric chloride for 2 minutes, followed by 3 rinses in sterile distilled water.
- 3.12.4 Substrate and inoculum dose: Steam sterilized soil substrate was air dried and potted in 7-8 kg capacity plastic pots. At the time of sowing, 50 gm of mycorrhizal inoculum comprising of 25 VAM infectious propagules gm⁻¹ was applied in the hole as per treatments. Each treatment was replicated three times. The pots were kept under controlled conditions and watered as and when required to field capacity. After germination one healthy plant were maintained in each pot. The observations were recorded after one month interval on plant height and collar diameter. After five months of sowing, the plants were harvested carefully and analyzed for the following parameters:
- 1. Biomass production in terms of root/ shoot fresh/ dry weight: Plants were washed in tap water followed by 0.1% HCL and repeated washing with de-ionized water. Plants were gently blotted on to a blotting paper and roots served from shoots and fresh weights were

recorded. Samples were dried in the oven at 68°C for 48 hours. Their dry weights were subsequently recorded.

- 2. Colonization index
- 3. Shoot length
- 4. Collar diameter
- 5. P content in the shoot and root tissues

3.13 Build up of VAM fungi in Trees/ Intercrops

Build up of above mentioned seven VAM species in Aonla, Ber, Chironji, Lasoda and important kharif (black gram, green gram and maize), zaid (black gram, green gram and maize) and rabi (gram, pea, maize and wheat) crops was studied in sand cultures. Tree/ crops were inoculated with VAM species and inoculated pots were kept under controlled conditions. Each treatment was replicated three times. The plants were irrigated with filtered water and half strength Hoagland solution was applied twice a week. Root and soil samples were taken at monthly intervals from inoculated pots and observations were recorded on following parameters:

- 1. Presence of arbuscules
- 2. Presence of vesicles
- 3. Presence of extrametrical hyphae
- 4. Presence of spores in extrametrical hyphae
- 5. Presence of spores in root
- 6. Colonization index
- 7. Spore count per 100 g soil
- 8. Presence of sporocarp

3.14 Determination of Soil Moisture

Soil samples were taken at 0-15 cm soil depth at 0.5 m distance from tree base at 30 days intervals from April to June, 2005. The soil moisture was recorded by gravimetric method (Lal Singh, 1987) using following formula:

Moisture $\% = F_{\underline{resh}}$ weight of soil – Dry weight of soil * 100

Dry weight of soil

Took exactly 50 g soil in weighted moisture boxes and dried the samples in an oven at 105° C for 12 hours. The weight of dried soil was taken after cooling.

3.15 Soil Reaction

The pH was measured with glass electrode pH meter using 1:2.5 soilwater ratio as originally suggested by Richards, 1954.

3.16 Electrical Conductivity

The 1:2.5 soil to water extracts was subjected to EC measurements and expressed as $1x10^5$ µs cm⁻¹ at 25^0 C as a measure of soluble salt content (Richards, 1954).

3.17 Determination of Organic Matter

The soil samples were ground and pass through a 0.2 mm (80 mesh sieve) and Walkley and Black's rapid titration procedure was used (Walkley and Black, 1934).

3.17.1 Reagents:

- 1. Concentrated H₂SO₄
- 2. Concentrated phosphoric acid (85%)
- 3. 1 N Potassium dichromate solution: dissolved 49.04 g of K₂Cr₂O₇ in water and made volume to one liter
- 4. N/2 Ferrous ammonium sulphate solution: dissolved 196.0 g of salt in water, added about 90 ml dilute H₂SO₄ and made volume to one liter

- 6. Diphenylamine indicator: dissolved 0.5 g of the indicator in 100 ml concentrated H₂SO₄ and stored in a coloured bottle.
- **3.17.2 Procedure:** Transferred 0.5 g of soil in a 500 ml conical flask and 10 ml of K₂Cr₂O₇ and 20 ml of concentrated H₂SO₄ were added to it. Shook the mixture for 5 minutes and kept it standing for 30 minutes. If the colour of the contents changed to green or yellowish green, added 10 ml K₂Cr₂O₇ and left for another 30 minutes. Diluted the mixture with 200 ml water and 10 ml of phosphoric acid (H₃PO₄) and 1 ml (15-20 drops) of diphenylamine indicator were added. A deep violet colour developed. Titrated with ferrous ammonium sulphate till the colour changed first to purple and finally to green. A blank experiment was also carried out.

3.17.3 Observations:

Weight of soil taken = W g

Volume of N/2 ferrous ammonium sulphate used = X ml

to reduce (neutralize) 10 ml of 1N K₂Cr₂O₇

(blank reading)

Volume of N/2 ferrous ammonium sulphate = Y ml

used to reduce (neutralize) excess of

1N K₂Cr₂O₇ (experimental reading)

3.17.4 Calculations:

Volume of N/2 ferrous ammonium sulphate = (X-Y) ml

equal to 1N K₂Cr₂O₇ required to oxidize

organic carbon present in the soil

Volume of 1N ferrous ammonium sulphate = (X-Y)/2 ml

equal to 1N K₂Cr₂O₇ required to oxidize

organic carbon present in the soil

 $1 \text{ ml } 1\text{N } \text{K}_2\text{Cr}_2\text{O}_7 = 0.003 \text{ g of carbon}$

 $(X-Y)/2 \text{ ml } 1N \text{ K}_2\text{Cr}_2\text{O}_7 = 0.003 \text{ x} (X-Y)$

2

Percentage of organic carbon

 $0.003(X-Y) \times 100$

2.W

= Z

Generally 58% carbon is present in the organic matter:

Therefore, percentage of organic matter = $Z \times 100/58$

 $= Z \times 1.724$

3.18 Plant Analysis for Phosphorus

Phosphorus in plant samples was determined by using Vanadomolybdo phosphoric acid yellow colour method (Jackson, 1973). Plant samples were dried in sun, then in oven at 80°C for two hours and ground to pass through a 1 mm sieve. The plant samples (approximately 200 g) were stored in polythene begs till further analysis.

3.18.1 Reagents:

- 1. Di-acid mixture: The mixture was prepared by mixing 800 ml nitric acid (HNO₃) with 200 ml per-chloric acid (HClO₄) in a winchister bottle.
- 2. Standard phosphorus solution: 50 ppm P stock solution was prepared by dissolving 0.2195 g of A.R. potassium di-hydrogen orthophosphate (KH₂PO₄) in 1 litre distilled water.
- Ammonium molybdate ammonium vanadate solution in HNO₃:
 Solution A: Dissolved 22.5 g ammonium molybdate in 400 ml of distilled water

Solution B: Dissolving 1.25 g of ammonium vanadate in 300 ml of boiling distilled water.

Solution A and solution B were added in 1 litre volumetric flask. These were cooled to room temperature, 250 ml of concentrated HNO₃ was added and the volume was made up to the mark.

3.18.2 Procedure: Digestion of plant sample in di-acid mixture: Transfer 0.5 g of oven dried plant sample in a digestion flask. Added 10 ml of di-acid to it

and the mixture was heated on a sand bath. The digestion was continued till a white residue was obtained. If the contents of the digestion flask dried before complete digestion, 5 ml of di-acid was added and digestion was continued until white colour was obtained. After digestion, the contents were cooled, diluted with water, filtered through Whatman No. 1 filter paper and the volume was made up to the mark in a 100 ml volumetric flask.

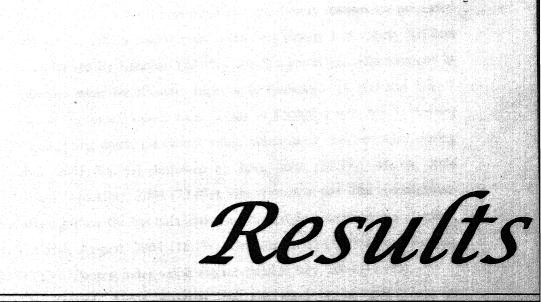
3.18.3 Preparation of standard curve: Transferred 0, 1, 2, 3, 4 and 5 ml of standard P solution to 50 ml volumetric flask to get 0, 1, 2, 3, 4 and 5 ppm of P respectively. Added 10 ml of vandate molybdate reagent to each flask. Made up the volume with de-ionized water, shook the contents of the volumetric flasks thoroughly and read absorbance of solutions after 30 minutes at 420 nm with spectrophotometer by using blue filter. Plotted absorbance against concentration to obtain the standard curve. The slope of the curve was determined and the concentration of the unknown solutions was calculated by using the equation.

Absorbance = Slope x Concentration

For analysis of plant samples, 5 ml of the digested aliquots were used instead of standard P solution.

3.19 Statistical Analysis

Treatment effects were determined by analysis of variance (ANOVA) using a completely randomize design. A significance level of 95% was applied. The graphs were prepared by using MS Excel or SYSTAT.



EXPERIMENTAL RESULTS

The present study was carried out with the aim to identify suitable VAM species for inoculation of Aonla (*Emblica officinalis* Gaertn.), Ber (*Zizyphus mauritiana* Lamk.), Chironji (*Buchanania lanzan* Spr.) and Lasoda (*Cordia myxa* Roxb.). To achieve this, a series of experiments on field surveys, identification of common VAM fungi in rhizosphere of above mentioned tree species, culturing, purification and multiplication of VAM fungi and screening of the fungi for improved seedling growth, were conducted. The results obtained from various experiments were statistically analyzed and are presented hereunder with appropriate tables and suitable graphs.

4.1 Field surveys:

4.1.1 Colonization index, spore count and species composition in rhizosphere of Aonla varieties: The data on colonization index in rhizosphere of Aonla varieties recorded during different seasons are presented in Table 4.1. Maximum colonization index was recorded in variety Krishna (22.7%), followed by Kanchan (20.0%), which were at par. Observations in these varieties were significantly superior to Chakaiya (16.5%) and NA-7 (16.3%) and the index values were at par in Chakaiya and NA-7. Among different sampling dates, maximum colonization-index was recorded during December, 2003 (26.9%), followed by June, 2004 (26.3%), March, 2004 (24.1%) and September, 2004 (22.6%), which were at par. The colonization-index was significantly less than above mentioned treatments during October, 2004 (16.6%), August, 2004 (16.1%), October, 2003 (14.7%) and August, 2003 (13.6%). Poorest index value was recorded in July, 2003 (11.1%).

In general, Aonla varieties did not show major differences in colonization-index. The data on spore count per 100 gm soil of VAM fungi in rhizosphere of Aonla varieties are presented in Table 4.2. The counts in

Table 4.1 Colonization index of VAM fungi in some Aonla (*Emblica officinalis* Gaertn.) varieties during different sampling periods

Date of	Colonization index in Aonla varieties					
sampling	Chakaiya	Kanchan	Krishna	NA-7	Mean	
July,	8.7*	11.9	12.3	11.6	11.1	
2003	$(17.1^{\#})$	(20.1)	(20.5)	(19.9)	(19.4)	
August,	15.7	14.2	14.9	9.8	13.6	
2003	(23.3)	(22.1)	(22.7)	(18.2)	(21.6)	
October,	14.9	18.4	13.8	12	14.7	
2003	(22.7)	(25.4)	(21.8)	(20.2)	(22.5)	
December,	26.1	34.3	24.6	22.7	26.9	
2003	(30.7)	(35.8)	(29.7)	(28.4)	(31.2)	
March,	21.8	17.9	31.4	25.0	24.1	
2004	(27.8)	(25.0)	(34.7)	(30.0)	(29.4)	
June,	21.7	28.9	31.1	23.3	26.3	
2004	(27.7)	(32.5)	(33.9)	(28.8)	(30.8)	
August,	13.7	15.6	17.5	17.8	16.1	
2004	(21.7)	(23.2)	(24.7)	(24.9)	(23.6)	
September,	14.8	23.7	38.6	16.2	22.6	
2004	(22.6)	(29.1)	(38.4)	(23.7)	(28.4)	
October,	13.2	18.4	23.4	12.2	16.6	
2004	(21.3)	(25.4)	(28.9)	(20.4)	(24.0)	
Mean	16.5	20 -	22.7	16.3		
	(23.9)	(26.5)	(28.4)	(23.8)		
		S. Em. <u>+</u>	C.D.			
			(0.05%)			
Variety		1.0	2.9			
Sampling date		1.5	4.3			
Variety * samplin	g date	3.1	NS			

^{*}Average of four replications
Figures in parenthesis indicate angular transformation values

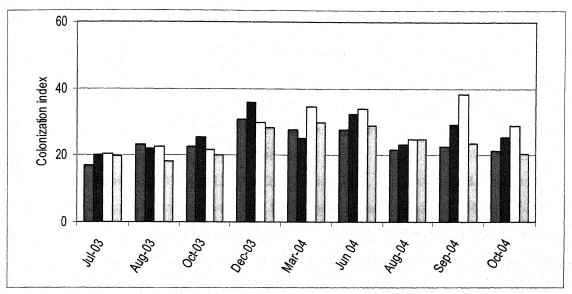
Table 4.2 Spore population of VAM fungi in rhizosphere of some Aonla (*Emblica officinalis* Gaertn.) varieties during different sampling periods

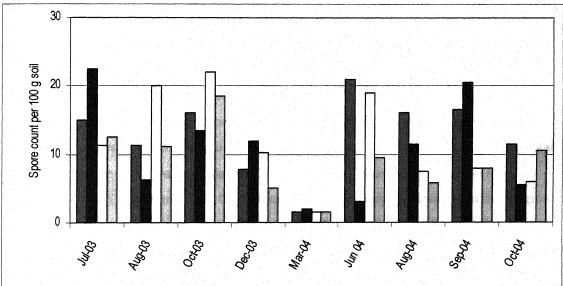
Date of sampling	ampling VAM spore count per 100 g soil in rhizosphere of A					
			varieties			
	Chakaiya	Kanchan	Krishna	NA-7	Mean	
July, 2003	15.0*	22.5	11.3	12.5	15.3	
August, 2003	11.3	6.3	20.0	11.3	12.2	
October, 2003	16.0	13.5	22.0	18.5	17.5	
December, 2003	7.8	12.0	10.3	5.0	8.8	
March, 2004	1.5	2.0	1.5	1.5	1.6	
June, 2004	21.0	3.0	19.0	9.5	13.1	
August, 2004	16.0	11.5	7.5	5.8	10.2	
September, 2004	16.5	20.5	8.0	8.0	13.3	
October, 2004	11.5	5.5	6.0	10.5	8.4	
Mean	12.9	10.8	11.7	9.2		
		S. Em. <u>+</u>	C.D.			
			(0.05%)			
Variety		1.2	NS			
Sampling date		1.7	4.9			
Variety * sampling	g date	3.5	9.7		-	

^{*}Average of four replications

Table 4.3 VAM species composition in rhizosphere of different Aonla (*Emblica officinalis* Gaertn.) varieties during different periods

Date of sampling	te of sampling Name of fungi Spore count of VAM fungi in rhizosphere of					
		Chakaiya	Kanchan	Krishna	NA-7	
October, 2003	Glomus I	6	4	2	16	28
	Glomus II	2	14	14	10	40
	Acaulospora I	20	6	16	12	54
	Acaulospora II	2	6	2	10	20
	Gigaspora White	0	0	0	0	0
	Sub total	30	30	34	48	142
December, 2003	Glomus I	9	7	2	3	21
	Glomus II	2	0	5	2	9
	Acaulospora I	6	0	0	1	7
	Acaulospora II	0	2	7	2	11
	Gigaspora White	0	1	0	0	1
	Sub total	17	10	14	8	49
March, 2004	Glomus I	4	4	3	3	14
	Glomus II	0 .	0	0	0	0
	Acaulospora I	0	2	0	0 -	2
	Acaulospora II	0	0	2	0	2
	Gigaspora White	0	0	0	1	1
	Sub total	4	6	5	4	19
June, 2004	Glomus I	14	2	24	16	56
	Glomus II	4	2	0	0	6
	Acaulospora I	8	0	12	2	22
	Acaulospora II	6	2	6	4	18
	Gigaspora White	2	0	0	0	2
	Sub total	34	6	42	22	104
August, 2004	Glomus I	23	5	5	10	43
	Glomus II	4	2	0	2	8
	Acaulospora I	1	1	2	0	4
	Acaulospora II	1	0	3	0	4
	Gigaspora White	0.	3	0	0	3
	Sub total	29	11	10	12	62
September, 2004	Glomus I	18	6	8	4	36
	Glomus II	6	18	4	2	30
	Acaulospora I	2	4	2	2	10
	Acaulospora II	0	0	0	0	0
	Gigaspora White	2	0	0	2	4
	Sub total	28	28	14	10	80
October, 2004	Glomus I	16	6	4	10	36
	Glomus II	6	4	0	4	14
	Acaulospora I	2	0	0	4	6
	Acaulospora II	0	0	2	0	2
	Gigaspora White	0	0	0	0	0
	Sub total	24	10	6	18	58
	Total	166	101	125	122	514





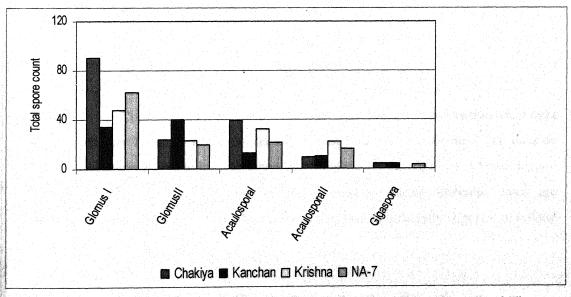


Fig.4. 1 Colonization-index, spore count and species composition of VAM fungi in rhizosphere of different Aonla(*Emblica officinalis* Gaertn.) varieties

rhizosphere of different varieties were at par, which ranged from 10.8 to 12.9. Among different sampling dates, maximum spore count was recorded during October 2003 (17.5 per 100 gm soil), followed by July 2003 (15.3 per 100 gm soil), September 2004 (13.3 per 100 gm soil) and June 2004 (13.1 per 100 gm soil), which were at par. The count during August 2003, August 2004, December 2003, and October 2004, were 12.2, 10.2, 8.8, and 8.4 spores per 100 gm soil, respectively and these were at par with count obtained during September 2004. The poorest count was obtained during March 2004 (1.6 per 100 gm soil). In general, the counts were directly related to soil moisture content, and it was more during rainy season than during drier periods.

VAM species composition in rhizosphere of different Aonla varieties are presented in Table 4.3. Five species belonging to three genera namely, *Glomus, Acaulospora* and *Gigaspora*, were common. Maximum total spore count was recorded for *Glomus* I (234), followed by *Glomus* II (107), *Acaulospora* I (105), and *Acaulospora* II (52). The poorest spore count was recorded for *Gigaspora* (11). Among different Aonla varieties, maximum total spore count was recorded in Chakaiya (166), followed by Krishna (125), NA-7 (122), and Kanchan (101). Among different sampling dates, maximum spore count was recorded during October 2003 (142), followed by June 2004 (104), September 2004 (80), August 2004 (62), October 2004 (58), March 2004 (56), and December 2003 (49). In general, *Glomus* I and *Glomus* II were predominant VAM species in rhizosphere of tested Aonla plants, followed by two *Acaulospora* species. A few spores of a whitish green *Gigaspora* species and a *Scutellospora* species were also recorded (Fig. 4.1). The better counts were recorded during rainy seasons than during drier periods.

4.1.2 Colonization index, spore count and species composition in Aonla variety Krishna under water-logged and normal conditions: The data on colonization index in rhizosphere of Aonla variety Krishna under water logged (during rainy season) and normal conditions during different dates are presented in Table 4.4. Colonization index was significantly superior in upland

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Table 4.4 Colonization index and spore count of VAM fungi in rhizosphere of Aonla (*Emblica officinalis* Gaertn.) variety Krishna under waterlogged and normal conditions during different sampling periods

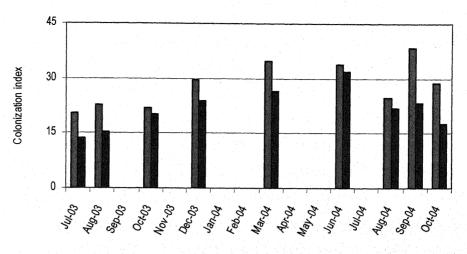
Date of sampling	Colo	nization inde	x in	VAM s	pore count per	100 g soil in
	Upland	Lowland	Mean	Upland	Lowland	Mean
	plants	plants		plants	plants	
July, 2003	12.3	5.6	8.6	11.3	8.8	10.0
	(20.5)	(13.6)	(17.0)			
August, 2003	14.9	7.1	10.8	20.0	7.5	13.8
	(22.7)	(15.4)	(19.1)			
October, 2003	13.8	12.1	12.9	22.0	11.5	16.8
	(21.8)	(20.3)	(21.0)			
December, 2003	24.6	16.5	20.4	10.3	4.8	7.5
	(29.7)	(23.9)	(26.8)			
March, 2004	32.4	20.2	26	1.5	3.0	2.2
	(34.7)	(26.60)	(30.6)			
June, 2004	31.1	28	29.5	17.8	2.0	9.9
	(33.9)	(31.9)	(32.9)			
August, 2004	17.5	14.1	15.7	7.5	9.8	8.6
	(24.7)	(22.0)	(23.3)			
September, 2004	38.6	15.7	26.4	8.0	13.0	10.5
	(38.4)	(23.3)	(30.9)			
October, 2004	23.4	9.2	15.6	6.0	5.5	5.8
	(28.9)	(17.6)	(23.2)			
Mean	22.7	13.6		11.6	7.3	
	(28.4)	(21.6)				
	S. Em. <u>+</u>	C.D.		S. Em. <u>+</u>	C.D.	
		(0.05%)			(0.05%)	
Location	0.9	2.6		1.3	3.7	
Date of sampling	2.0	5.6		2.8	7.9	
Location * date	2.8	7.9		3.9	11.1	
of sampling						
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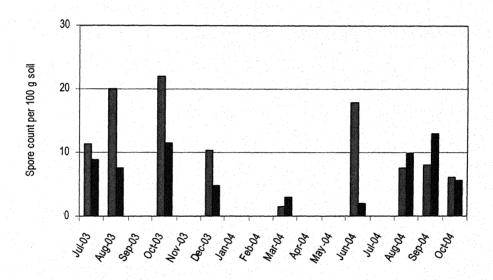
^{*}Average of four replications

[#] Figures in parenthesis indicate angular transformation values

Table 4.5 VAM species composition in rhizosphere of upland and lowland Aonla (*Emblica officinalis* Gaertn.) plants recorded at different sampling periods

Date of sampling	Name of fungi		f VAM fungi in phere of	Total
		Upland plants	Lowland plants	
October, 2003	Glomus I	2	2	4
	Glomus II	14	4	18
	Acaulospora I	16	2	18
	Acaulospora II	2	0	2
	Sub Total	34	8	42
December, 2003	Glomus I	2.	2	4
	Glomus II	5	1	6
	Acaulospora I	0	0	0
	Acaulospora II	7	0	7
	Sub Total	14	3	17
March, 2004	Glomus I	3	6	9
	Glomus II	0	0	0
	Acaulospora I	0	0	0
	Acaulospora II	2	0	2
	Sub Total	5	6	11
June, 2004	Glomus I	24	2	26
	Glomus II	0	3	3
	Acaulospora I	12	0	12
	Acaulospora II	6	0	6
	Sub Total	42	5	47
August, 2004	Glomus I	5	12	17
j	Glomus II	0 0	4	4
	Acaulospora I	2	0	2
	Acaulospora II	3	1	4
	Sub Total	10	17	27
September, 2004	Glomus I	8	12	20
	Glomus II	4	4	8
	Acaulospora I	2	0,	2
	Acaulospora II	0	0	0
	Sub Total	14	16	30
October, 2004	Glomus I	4	0	4 4
	Glomus II	0	6	6
	Acaulospora I	0	0	0
	Acaulospora II	2	0	2
	Sub Total	6	6	12
	Grand Total	125	61	186





VAM species composition

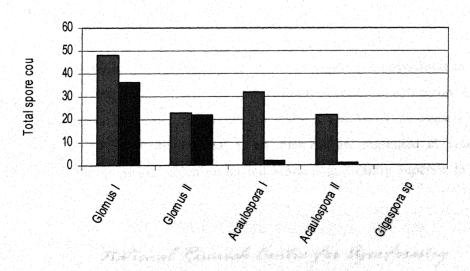


Fig. 4.2 Colonization index, spore count and species composition of VAM fungi in Aonla (Emblica officinalis Gaertn.) variety Krishna under water logged and normal

plants (22.7%) as compared to water logged plants (13.6%). Among different sampling dates, maximum colonization-index was recorded during June 2004 (29.5%), followed by September 2004 (26.4%), March 2004 (26.0%), which were at par. The index values during December 2003 (20.4%), August 2004 (15.7%), and October 2004 (15.6%) were at par. The poorest colonization index was recorded in October 2003 (12.9%), August 2003 (10.8%) and July 2003 (8.6%). As already indicated the colonization-index values were more during dry sampling periods as compared to rainy season. The data on spore count per 100 g soil in rhizosphere of Aonla varieties Krishna under water logged and normal conditions are presented in Table 4.4. The spore population per 100 g soil of AM fungi was significantly more in upland plants (11.6) than in lowland plants (7.3). Among different sampling dates, maximum spore count was recorded during October 2003 (16.8), followed by August 2003 (13.8), September 2004 (10.5), July 2003 (10.0), June 2004 (9.9), August 2004 (8.6) and December 2003 (7.5), which were at par. The poorest counts were obtained during October 2004 (5.8) and March 2004 (2.2), which were at par. The data on VAM species composition in rhizosphere of Aonla varieties Krishna under water logged and normal conditions are presented in Table 4.5. Glomus I (84) recorded maximum total spore count, followed by Glomus II (45), Acaulospora I (34) and Acaulospora II (23). Total spore count was more in upland plants (125) than lowland plants (61). Among different sampling dates, maximum spore count was recorded during June 2004 (47), followed by October 2003 (42), September 2004 (30), August 2004 (27), December 2003 (17). The lowest spore counts were recorded in October 2004 (12) and March 2004 (11).

4.1.3 Colonization index, spore count and species composition in Aonla rhizosphere variety NA-7 with and without wheat as an intercrop: Data on colonization index and spore count per 100 g soil in Aonla rhizosphere variety NA-7 with and without wheat as an intercrop are presented in Table 4.6. During crop period, colonization index was significantly superior in Aonla

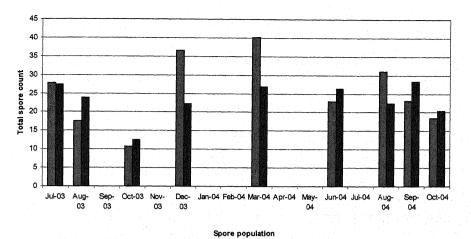
Table 4.6 Colonization index and spore count of VAM fungi in rhizosphere of Aonla variety NA-7 with and without wheat as inter-crop

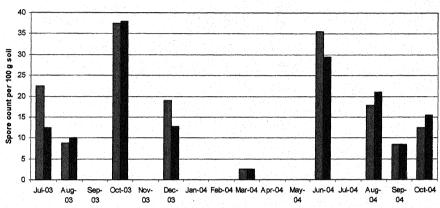
Date of sampling	Colonizat	ion index in	Aonla		oore count pe	r 100 g soil in Aonla
	With	Without	Mean	With	Without	Mean
	wheat	wheat		wheat	wheat	
Pre crop period						
July,	27.8*	27.5	27.7	22.5*	12.5	17.5
2003	$(31.8^{\#})$	(31.6)	(31.7)			
August,	17.6	23.8	20.7	8.8	10.0	9.4
2003	(24.8)	(29.2)	(27.0)			
October,	10.8	12.5	12.2	37.5	38.0	37.8
2003	(20.1)	(20.7)	(20.4)			
Mean	18.7	20.9	(, , ,	22.9	20.2	
	(25.6)	(27.2)				
Crop period		(
December,	36.6	22.2	29.2	19.0	12.8	15.9
2003	(37.2)	(28.1)	(32.7)			
March,	40.2	26.9	33.4	2.5	2.5	2.5
2004	(39.3)	(31.2)	(35.3)			
Mean	38.4	24.6	(0.00)	10.8	7.6	
	(38.3)	(29.7)				
Post crop period	(50.5)	(=>)				
June,	23.0	26.4	24.7	35.5	29.5	32.5
2004	(28.6)	(30.9)	(29.8)			
August,	31.0	22.4	26.6	17.8	21.0	19.4
2004	(33.8)	(28.2)	(31.0)			
September,	23.1	28.3	25.6	8.5	8.5	8.5
2004	(28.7)	(32.1)	(30.4)			
October,	18.4	20.4	19.4	12.5	15.5	14.0
2004	(25.4)	(26.8)	(26.1)			
Mean	23.7	24.3	(====)	18.6	18.6	
	(29.1)	(29.5)				
		S. Em. <u>+</u>	C.D. (0	0.05%)	S. Em. <u>+</u>	C.D.(0.05%)
Pre-crop period						
Treatment		1.8	NS		3.7	NS
Date of sampling		2.2	6.7		4.6	13.6
Treatment*date of	f sampling	3.2	NS		6.5	NS
Crop period						
Treatment		2.4	7.5		1.8	NS
Date of sampling		2.4	NS		1.8	5.5
Treatment*date of	f sampling	3.5	NS		2.5	NS
Post crop period						
Treatment		2.3	NS		2.2	NS
Date of sampling		3.2	NS		3.0	8.9
Treatment*date of	f sampling	4.5	NS		4.3	NS

^{*}Average of four replications
Figures in parenthesis indicate angular transformation values

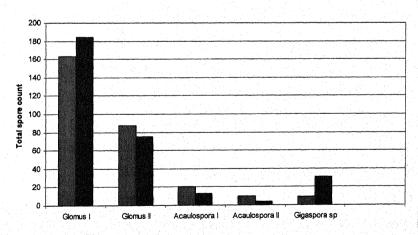
Table 4.7 VAM species composition in rhizosphere of Aonla (*Emblica officinalis* Gaertn.) plants, grown with and without wheat as an intercrop during different periods

Date of sampling	Name of fungi		of VAM fungi in osphere grown	Total
	•	With wheat	Without wheat	
Pre crop period				
October, 2003	Glomus I	34	64	98
	Glomus II	52	38	90
	Acaulospora I	6	4	10
	Acaulospora II	6	0	6
	Gigaspora white	0	6	6
	Sub total	98	112	210
Crop period				
December, 2003	Glomus I	26	12	38
	Glomus II	2	18	20
	Acaulospora I	1	1	2
	Acaulospora II	0	0	0
	Gigaspora white	1	6	7
	Sub total	30	37	67
March, 2004	Glomus I	6	6	12
	Glomus II	0	1	1
	Acaulospora I	Ö	Ô	Ô
	Acaulospora II	0	0	0
	Gigaspora white	ŏ	3	3
	Sub total	6	10	16
Post crop period				- 1
June, 2004	Glomus I	48	50	98
June, 2004	Glomus II	20	14	34
	Acaulospora I	6	2	8
	Acaulospora II	4	$\frac{2}{4}$	8
	Gigaspora white	8	6	14
	Sub total	86	76	162
August, 2004	Glomus I	25	30	55
August, 2004	Glomus II	5	0	5
	Acaulospora I	3	${f 2}$	5
	Acaulospora II	0	0	0
	Gigaspora white	0	0	0
	Sub total	33	32	65
Contombor 2004	Glomus I	33 8	32 8	16
September, 2004	Glomus II	0	4	4
			0	0
	Acaulospora I	0	0	0
	Acaulospora II			0
	Gigaspora white	0 8	0 12	20
0-4-1 0004	Sub total		12	30
October, 2004	Glomus I	16		8
	Glomus II	8	0 1	8
	Acaulospora I	4	4	
	Acaulospora II	0	0	0
	Gigaspora white	0	10	10
	Sub total	28	28	56 506
	Total	289	307	596









With WheatWithout wheat

Fig. 4.3 Colonization index, spore count and species composition of VAM fungi in rhizosphere of Aonla (*Emblica officinalis* Gaertn.) variety NA-7 with and without wheat as an intercrop

plants with wheat (38.4%) than in Aonla plants grown without wheat (24.6%). While during pre- crop and post- crop periods, it was at par in both treatments i.e. with wheat (18.7%, 23.7%) and without wheat (20.9%, 24.3%), respectively. The observations on VAM spore count per 100 g soil from rhizosphere of Aonla plants grown with wheat were at par with respective observations on Aonla plants grown without wheat, during all above mentioned crop periods. The data on VAM species composition in Aonla rhizosphere variety NA-7 with and without wheat as an intercrop are presented in Table 4.7. Glomus I (347) recorded maximum total spore count, followed by Glomus II (162), Gigaspora (40), Acaulospora I (33) and Acaulospora II (14). Total spore count was slightly less in agroforestry plot (289) than control plot (307). Among different sampling dates, maximum spore count was recorded during October 2003 (210), followed by June 2004 (162), December 2003 (67), August 2004 (65), October 2004 (56) and September 2004 (20). The lowest spore count was recorded in March 2004 (16). Thus, the results showed that VAM species composition did not show any qualitative changes, however some quantitative changes in species composition were recorded (Fig. 4.3).

4.1.4 Colonization index, spore count and species composition in rhizosphere of Ber varieties: The data on colonization index in rhizosphere of Ber varieties recorded during different seasons are presented in Table 4.8. Maximum colonization index was recorded in Banarsi karaka (32.1%) and Seo (32.1%), followed by Ghot (30.0%), Makor (28.6%), Jharberi (28.1%) and Desi (27.8%). The poorest index value was recorded in Gola (24.3%). However, the difference in the colonization index of different Ber varieties were non-significant. Among different sampling dates, September 2004 (32.1%) recorded maximum colonization-index, followed by March 2005 (31.6%), June 2005 (30.8%) and July 2004 (29.5%), which were at par. The poorest colonization-index was recorded during October 2004 (21.5%), which was significantly less than above mentioned treatments. The data on spore

Table 4.8 Colonization index and VAM spore counts in different Ber (Zizyphus mauritiana Lamk.) varieties and its wild relatives.

Date of Colonization index and VAM spore counts in						Mean		
sampling	Banarasi	Gola	Seo	Desi	Ghot	Jharberi	Makor	
	Karaka							
Colonization inde						-		
July,	25.3 [*]	30.0	37.4	39.1	24.9	22.4	28.8	29.5
2004	$(30.2^{\#})$	(33.2)	(37.7)	(38.7)	(29.9)	(28.2)	(32.4)	(32.9)
September,	22.1	17.2	38.3	33.6	29.7	43.1	43.8	32.1
2004	(28.0)	(24.5)	(38.2)	(35.4)	(33.0)	(41.0)	(41.4)	(34.5)
October,	19.0	13.5	20.8	13.9	40.5	18.4	28.0	21.5
2004	(25.8)	(21.5)	(27.1)	(21.9)	(39.5)	(25.4)	(31.9)	(27.6)
March,	61.5	29.9	44.5	19.7	18.6	28.9	23.1	31.6
2005	(51.6)	(33.1)	(41.8)	(26.3)	(25.5)	(32.5)	(28.7)	(34.2)
June,	36.3	33.6	21.8	36.1	38.5	29.7	20.9	30.8
2005	(37.0)	(35.4)	(27.8)	(36.9)	(38.3)	(33.0)	(27.2)	(33.7)
Mean	32.1	24.3	32.1	27.8	30.0	28.1	28.6	
	(34.5)	(29.5)	(34.5)	(31.8)	(33.2)	(32.0)	(32.3)	
Spore count per l	100 g soil		, ,					
July,	104.5*	66.0	42.5	57.0	82.0	58.0	44.0	64.9
2004								
September,	16.0	26.0	17.0	17.5	18.5	13.0	19.5	18.2
2004								
October,	11.5	7.0	5.0	9.5	21.5	15.5	15.5	12.2
2004								
March,	4.0	5.5	6.5	5.0	11.5	19.5	15.5	10.0
2005								
June,	11.5	24.5	5.5	7.0	10.5	6.0	10.5	10.8
2005								
Mean	29.5	25.8	15.3	19.2	28.8	22.4	21.0	
			Colonizat	tion index		Spore p	opulation	
			S. Em.	+ C.D.	(0.05%)	S. Em	. <u>+</u> C.D.	(0.05%)
Variety			1.8	_ NS		3.4	10.0	
Date of sampling			1.5	4.1		2.9	8.1	
Date of sampling	* variety		3.9	11.0)	7.7	21.4	1 1 1 1 X

^{*}Average of four replications.
#Figures in parenthesis indicate angular transformation values.

Table 4.9 VAM species composition in Ber (*Zizyphus mauritiana* Lamk.) rhizosphere at selected sites during different sampling periods

Date of	VAM species			Spore c	ount in	Ber rhizo	sphere		
sampling		Banarasi	Desi	Gola	Seo	Ghot	Jharberi	Makor	Total
		karaka			1				
July,	Glomus I	56	48	65	18	61	65	31	344
2004	Glomus II	1	0	0 .	2	0	3	1	7
	Glomus mosseae	0	0	0	0	3	0	0	3
	Acaulospora I	26	1	1	1	32	10	10	81
	Acaulospora II	1	3	0	1	1	1	0	7
	Gigaspora sp	0	0	0	0	3	6	0	9
	Sub total	84	52	66	22	100	85	42	451
September	Glomus I	1	6	12	3	10	4	6	42
2004	Glomus II	3	8	3	5	4	4	6	33
	Glomus mosseae	0	0	0	0	0	0	0	0
	Acaulospora I	0	0	0	0	1	3	5	9
	Acaulospora II	1	0	3	2	4	2	3	15
	Gigaspora sp	0	0	0	0	0	0	0	0
	Sub total	5	14	18	10	19	13	20	99
October,	Glomus I	2	2	2	2	7	5	13	33
2004	Glomus II	0	1	1	1	5	7	3	18
	Glomus mosseae	0	0	0	0	0	0	0	0
	Acaulospora I	0	0	0	0	7	1	1	9
	Acaulospora II	3	1	1	0	4	1	1	11
	Gigaspora sp	0	0.0	0	0	0	3	0 0	3
	Sub total	5	4	4	3	23	17	18	74
March,	Glomus I	2	2	2	4	2	9	2	23
2005	Glomus II	0	0	0	0	2	9	2	13
	Glomus mosseae	0	0	0	0	0	0	0	0
	Acaulospora I	0	1	0	0	1	1	1	4
	Acaulospora II	0	0	0 0	1	0	2	1	4
	Gigaspora sp	0	0	0	0	0	0	0	0
	Sub total	2	3	2	5	5	21	6	44
June,	Glomus I	12	2	20	2	0	0	18	54
2005	Glomus II	0	4	0	0	0	0	0	4
	Glomus mosseae	0	0	0	0	0	0	0	0
	Acaulospora I	ŏ	10	44	4	16	12	2	88
	Acaulospora II	Ö	0	10	0	0	0	2	12
	Gigaspora sp	4	0	6	0	0	Ŏ	0	10
	Sub total	16	16	80	6	16	12	22	168
		112	89	170	46	163	148	108	836
	Total	114	07	1/0	40	105	170	100	050

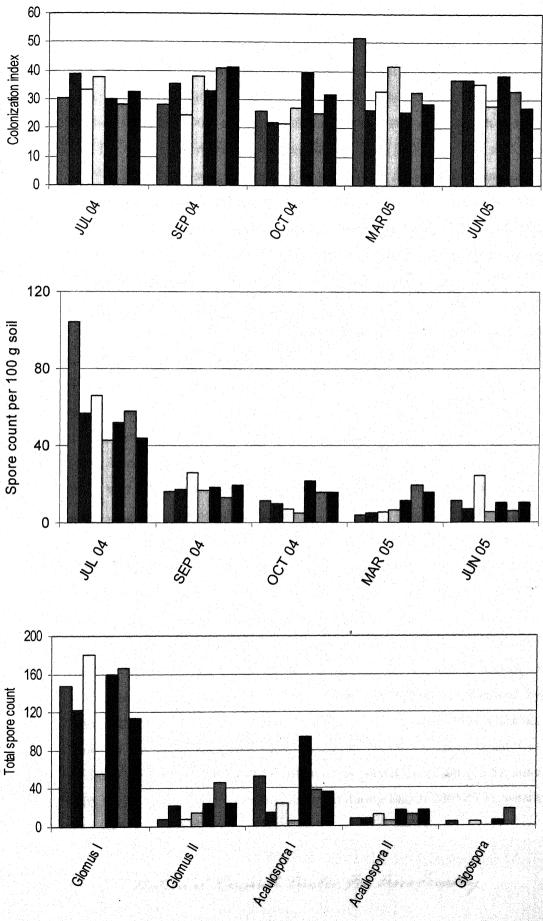


Fig.4.4 Colonization-index, spore count and species composition of VAM fungi in rhizosphere

count per 100 g soil in rhizosphere of Ber varieties are presented in Table 4.8. Maximum VAM spore count was recorded in Banarsi Karaka (29.5 per 100 g soil), followed by Ghot (28.8 per 100 g soil), Gola (25.8 per 100 g soil), Jharberi (22.4 per 100 g soil) and Makor (21.0 per 100 g soil), which were at par. The poorest spore count was recorded in Desi (19.2 per 100 g soil) and Seo (15.3 per 100 g soil) which were at par. Among different sampling dates, maximum spore count was recorded in July 2004 (64.9 per 100 g soil) which was significantly superior to other readings. The value during September 2004 (18.2 per 100 g soil), October 2004 (12.2 per 100 g soil), June 2005 (10.8 per 100 g soil), were at par. The lowest reading was recorded in March 2005 (10.0 per 100 g soil). VAM species composition in rhizosphere of different Ber varieties are presented in Table 4.9. Maximum total spore count was recorded for Glomus 1 (496), followed by Acaulospora 1 (191), Glomus II (75), Acaulospora II (49) and Gigaspora (11). The poorest spore count was recorded for Glomus mosseae (3). Among different Aonla varieties, maximum total spore count was recorded in Gola (170), followed by Ghot (163), Jharberi (148), Banarsi Karaka (112), Makor (108) and Desi (89). The poorest spore count was recorded for Seo (46). Among different sampling dates, maximum spore count was recorded during July 2004 (451), followed by June 2005 (168), September 2004 (99), October 2004 (74) and March 2005 (74).

4.1.5 Colonization index, spore count and species composition in rhizosphere of Chironji: The data on colonization index and spore count in rhizosphere of Chironji during different seasons are presented in Table 4.10. Differences in colonization index values at Jakhlon (27.0%) and Nilkanthh (18.9%) were non-significant. Among different sampling dates, maximum colonization index was recorded during June 2005 (29.0%), followed by March 2005 (23.1%), July 2004 (22.2%), and September 2004 (17.6%). However the differences were non-significant. Maximum spore count was recorded during July 2004 (19.5), followed by September 2004 (13.5), June 2005 (11.8). The poorest count was recorded during March 2005 (5.3), which

Table 4.10 Colonization index and count of VAM spores in rhizosphere of Chironji (Buchanania lanzan Spr.) at different sites

Date of	Colo	nization index	at	VAM spo	re count per 1	00 g soil
sampling					at	
	Jakhlon	Nilkanthh	Mean	Jakhlon	Nilkanthh	Mean
July,	35.1*	11.6	22.2	11	28	19.5
2004	$(36.3^{\#})$	(19.9)	(28.1)			
September,	17.2	18.1	17.6	13	14	13.5
2004	(24.5)	(25.2)	(24.8)			
March,	20.0	26.2	23.1	5.5	5	5.25
2005	(26.6)	(30.8)	(28.7)			
June,	37.6	20.9	29.0	12.5	11	11.75
2005	(37.9)	(27.2)	(32.6)			
Mean	27.0	18.9		10.5	14.5	
	(31.3)	(25.8)				
	S.Em. <u>+</u>	C.D.		S.Em. <u>+</u>	C.D.	
		(0.05%)			(0.05%)	
Site	2.8	NS		1.9	NS	
Sampling date	3.9	NS		2.6	7.7	
Interaction	5.6	NS		3.7	NS	

^{*}Average of four replications
Figures in parenthesis indicate angular transformation values

Table 4.11 VAM species composition in Chironji (*Buchanania lanzan* Spr.) rhizosphere at selected sites during different sampling periods

Date of sampling	VAM species	Spore cour	t in Chironji rhizo	sphere
		Jakhlon forest	Nilkanthh	Total
		nursery	temple	
July, 2004	Glomus I	3	26	29
	Glomus II	3	3	6
	Acaulospora I	0	2	2
	Acaulospora II	0,	0 4, 4	0
	Glomus mosseae	1	0	1
	Sub total	7	31	38
September, 2004	Glomus I	5	5	10
_	Glomus II	3	7	10
	Acaulospora I	0	0	0
•	Acaulospora II	0	0	0
	Gigaspora sp.	0	1	1
	Sub total	8	13	21
March, 2005	Glomus I	4	0	4
	Glomus II	1	2	3
	Acaulospora I	0	0	0
	Acaulospora II	0	0	0
	Sub total	5	2	7
June, 2005	Glomus I	10	8	18
	Glomus II	4	6	10
	Acaulospora I	0	2	2
	Acaulospora II	0	2	2
	Sub total	14	18	32
	Total	34	64	98

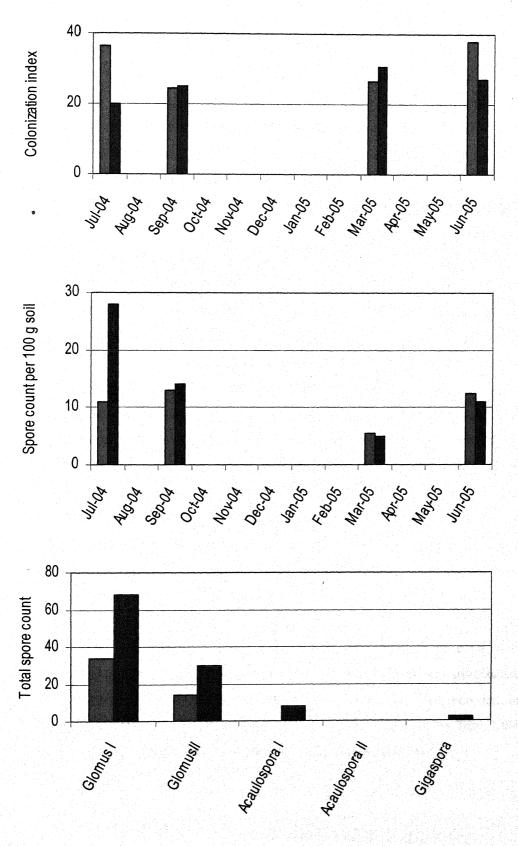


Fig. 4.5 Colonization-index, spore count and species composition of VAM fungi in rhizosphere of Chironii

was significantly less than September 2004 value. The data on species composition in Chironji recorded during different seasons are presented in Table 4.11. Maximum total spore count was recorded for *Glomus* 1 (61), followed by *Glomus* II (29), *Acaulospora* 1 (4) and *Acaulospora* II (2). The poorest counts were in *Gigaspora* (1) and *Glomus mosseae* (1). Total spore counts were 64 and 34 at Nilkanthh and Jakhlon, respectively. Among different dates, maximum spore count was in July 2004 (38), followed by June 2005 (32), September 2004 (21). The poorest spore count was during March 2005 (7).

4.1.6 Colonization index, spore count and species composition in Lasoda:

The data on colonization index and spore count in Lasoda recorded during different seasons are presented in Table 4.12 and Fig. 4.6. Maximum colonization index was recorded at NRCAF, silvipasture site (32.9%), followed by NRCAF, block plantation and Nareta (16.9), which were at par. Among different sampling dates, maximum colonization index was recorded during June 2005 (27.2%), followed by September 2004 (25.0%), July 2004 (23.1%) and October 2004 (22.1%). The poorest index was recorded in March 2005 (21.6%). However, the differences were non-significant. Maximum spore count was recorded during July 2004 (27.6), followed by September 2004 (11.8) and June 2005 (8.9). The poorest count was recorded during March 2005 (3.5). The data on species composition in rhizosphere of Lasoda recorded during different seasons are presented in Table 4.13. Maximum total spore count was recorded for Glomus 1 (75), followed by, Glomus II (36) and Acaulospora 1 (24). Poorest total count was in Acaulospora II (1) and Gigaspora (1). Among different Lasoda sites, maximum spore count was recorded in NRCAF, block plantation (77), followed by NRCAF, silvipasture site (60) and Nareta village (0). Maximum spore count was recorded in October 2004 (39) among different sampling dates, followed by July 2004 (38), September 2004 (34), June 2005 (22) and March 2005 (4).

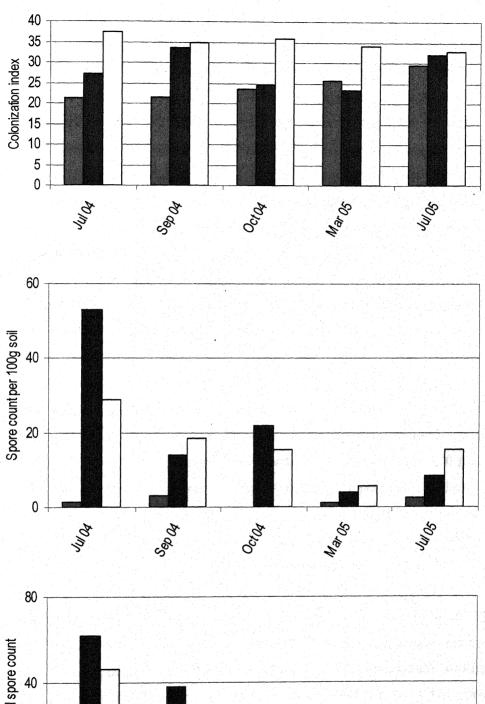
Table 4.12 Colonization index and count of VAM spores in rhizosphere of Lasoda (Cordia myxa Roxb.) at different sites

Date of		Colonization	n index in		Spc	re count per	100 g soil	in
sampling	Nareta	NRCAF	NRCAF	Mean	Nareta	NRCAF	NRCAF	Mean
		Block	Silvi-			Block	Silvi-	
		plantation	pasture			plantation	pasture	
July,	13.3	20.9	37.1	23.1	1.5	53.0	29.0	27.6
2004	(21.4)	(27.2)	(37.5)	(28.7)				
September,	13.5	30.6	32.7	25.0	3.0	14.0	18.5	11.8
2004	(21.6)	(33.6)	(34.9)	(30.0)				
October,	16.2	18.5	34.2	22.1	· -	· - .	-	
2004	(23.7)	(24.7)	(35.8)	(28.1)				
March,	18.7	15.8	31.4	21.6	1.0	4.0	5.5	3.5
2005	(25.6)	(23.4)	(34.1)	(27.7)				
June,	24.4	28.1	29.2	27.2	2.5	8.5	15.5	8.9
2005	(29.6)	(32.0)	(32.7)	(31.4)				
Mean	16.9	22.4	32.9		2.0	20.3	15.4	
	(24.3)	(28.2)	(35.0)					
		S.Em.	C.D.		S.Em.	C.D.		
		<u>+</u>	(0.05%)		<u>±</u>	(0.05%)		
Sites		1.7	4.8		3.5	10.1		
Sampling da	ate	1.9	NS		4.1	11.6		
Interaction		3.8	NS		7.1	20.1		

^{*}Average of four replications
Figures in parenthesis indicate angular transformation values

Table 4.13 VAM species composition in Lasoda (*Cordia myxa* Roxb.) rhizosphere at selected sites during different sampling periods

Date of	VAM species	Spore c	ount in Lasod	a rhizospher	e
sampling		Nareta,	Field 1,	Field 2,	Total
		Datia	NRC	NRC	
July,	Glomus I	0	23	5	28
2004	Glomus II	0	1	0	1
	Acaulospora I	0	7	1	8
	Acaulospora II	0	1	0	1
	Sub total	0	32	6	38
September,	Glomus I	0	1	8	9
2004	Glomus II	0	9	10	19
	Acaulospora I	0	3	2	5
	Acaulospora II	0	0	0	0
	Gigaspora sp.	0	0	1	1
	Sub total	0	13	21	34
October,	Glomus I	0	16	6	22
2004	Glomus II	0	7	7	14
	Acaulospora I	0	2	1	3
	Acaulospora II	0	0	0	0
	Sub total	0	25	14	39
March,	Glomus I	0	3	1	4
2005	Glomus II	0	0	0	0
	Acaulospora I	0	0	0	0
	Acaulospora II	0	0	0	0
	Sub total	0	3	1	4
June,	Glomus I	0	2	10	12
2005	Glomus II	0	0	2	2
	Acaulospora I	0	2	6	8
	Acaulospora II	0	0	0	0
	Sub total	0	4	18	22
	Total	0	77	60	137



Total spore count of the count

Fig.4.6 Colonization-index, spore count and species composition of VAM fungi in rhizosphere of Lasoda

4.2 Effect of soil types on VAM activity:

Effect of soil types on mycorrhization of Aonla rhizosphere by 4.2.1 VAM fungi: The results on effect of soil on colonization index, in rhizosphere of Aonla are presented in Table 4.14. Maximum colonization index was recorded in black soil (24.1%), which was at par with lateritic soil (20.1%). The index was poorest in red soil (16.7%). Observation in black soil was significantly more than red soil. Among different sampling dates, maximum colonization-index was recorded during June 2004 (31.5%), followed by March 2004 (28.6%) and December 2003 (24.9%), which were at par. The index values during October 2004 (21.4%), August 2004 (20.5%), September 2004 (18.4%), October 2003 (15.3%) and August 2003 (15.3%) were at par. Poorest colonization index was recorded in July 2003 (11.6%). In general, the colonization-index was inversely proportional to soil moisture content and it was more during dry sampling periods as compared to wet periods of the year. The data on spore count per 100 g soil in rhizosphere of Aonla variety NA-7 in different soil types during different sampling periods are shown in Table 4.15. Maximum VAM spore count was recorded in lateritic soil (15.9 per 100 g soil), which was significantly superior to black soil (11.3 per 100 g soil). The poorest spore count was recorded in red soil (9.6 per 100 g soil). Among different sampling dates, maximum spore count was recorded in October 2003 (33.5), which was significantly more than other readings. The spore count per 100 gm soil during August 2004 (13.4), September 2004 (12.0), June 2004 (11.7), December 2003(11.1), October 2004 (9.7), July 2003 (8.3) and August 2003 (6.7) which were at par. The lowest reading was recorded in March 2004 (3.5). Maximum biological diversity for VAM fungi was recorded in lateritic soil as compared to other two tested soil types and the spore count was more during rainy seasons than other drier months. The data on VAM species composition of Aonla rhizosphere in three different soil types during different sampling periods are presented in Table 4.16. Glomus 1 (319) recorded maximum total spore count, followed by Glomus II (165), Acaulospora 1

(122), and Acaulospora II (106). The poorest spore count was recorded for Gigaspora (7). Among different soil types, maximum total spore count was recorded in lateritic soil (376), followed by black soil (221) and red soil (122). Among different sampling dates, maximum spore count was recorded during October 2003 (320), followed by June 2004 (83), August 2004 (76), December 2003 (74). September 2004 (72), October 2004 (66) and March 2004 (28), In general, better counts were recorded during rainy seasons as compared to drier months. The data on pH, EC and percent organic content of soil samples taken from basins of Aonla (variety NA-7) growing in different soil types are presented table 4.17. Soil pH values in black soil, lateritic soil and red soil veried in narrow range (5.88 to 5.94). Maximum EC was recorded in black soil (49 µS cm⁻¹), followed by lateritic soil (39 µS cm⁻¹) and red soil (38 µS cm⁻¹). Maximum percent organic content was recorded in black soil (1.53 %), followed by red soil (1.20 %) and Lateritic soil (1.90 %). Detailed information on soil pH, EC and percent organic content of all marked trees is presented in appendix V.

4.2.2 Effect of soil moisture and soil temperature: Results on effect of soil moisture, soil surface temperature and soil temperature at 10 cm depth during summer months on colonization index of Aonla in different soil types are shown in Table 4.18. Maximum colonization was recorded in lateritic soil (27.9%), which was significantly more than colonization in red (21.2%) and black soils (17.9%). The index significantly increased from March 2005 (21.9%) to April 2005 (27.4%), significantly reduced from April 2005 to May 2005 (19.3%) and the observations during May 2005 and June 2005 (22.0%) were at par. In black soil, observations on colonization index during different months remained at par. In lateritic soil, the index values, significantly increased from March 2005 to April 2005 then significantly decreased from April 2005 to May 2005 and were at par during May 2005 and June 2005. The trend in red soil was similar to lateritic soil except that the value was significantly more during June 2005 than May 2005 value. Maximum soil

Table 4.14 Colonization index of VAM fungi in Aonla (*Emblica officinalis* Gaertn.) variety NA-7 in different soil types during different sampling periods

Date of sampling		Colonization	n index in	
	Black soil	Lateritic soil	Red soil	Mean
July,	13.6	9.3	12.3	11.6
2003	$(21.6^{\#})$	(17.7)	(20.5)	(19.9)
August,	16.3	19	10.2	15
2003	(23.8)	(25.8)	(18.6)	(22.7)
October,	17	16.5	12.5	15.3
2003	(24.3)	(23.9)	(20.7)	(23.0)
December,	26.1	24.6	24.6	24.9
2003	(30.7)	(29.7)	(29.7)	(29.9)
March,	25.2	34.1	27	28.6
2004	(30.1)	(35.7)	(31.3)	(32.3)
June,	47.8	21.7	26.3	31.5
2004	(43.7)	(27.7)	(30.8)	(34.1)
August,	29.7	14.2	18.8	20.5
2004	(33.0)	(22.1)	(25.7)	(26.9)
September,	13.7	25.3	17.1	18.4
2004	(21.7)	(30.2)	(24.4)	(25.4)
October,	32.4	20.7	12.7	21.4
2004	(34.7)	(27.0)	(20.8)	(27.5)
Mean	24.1	20.1	16.7	
	(29.4)	(26.6)	(24.7)	
		S. Em. <u>+</u>	C.D.	
			(0.05 %)	
Soil type		1.1	3.1	
Sampling date		1.9	5.4	
Soil type * sampling	date	3.3	9.3	

*Average of four replications

[#] Figures in parenthesis indicate angular transformation values

Table 4.15 Spore count of VAM fungi in rhizosphere of Aonla (*Emblica officinalis* Gaertn.) variety NA-7 in different soil types during different sampling periods

	VAM spore cour	nt per 100 g soil	in
Black soil	Lateritic soil	Red soil	Mean
2.5*	10.0	12.5	8.3
2.5	3.8	13.8	6.7
40.0	42.0	18.5	33.5
13.3	15.8	4.3	11.1
5.5	3.5	1.5	3.5
3.0	22.5	9.5	11.7
16.5	18.0	5.8	13.4
13.5	14.5	8.0	12.0
5.0	13.5	10.5	9.7
11.3	15.9	9.6	
	S. Em. <u>+</u>	C.D.	
		(0.05 %)	
	1.5	4.4	
	2.7	7.6	
ng date	4.6	13.1	
	2.5* 2.5 40.0 13.3 5.5 3.0 16.5 13.5 5.0 11.3	Black soil Lateritic soil 2.5* 10.0 2.5 3.8 40.0 42.0 13.3 15.8 5.5 3.5 3.0 22.5 16.5 18.0 13.5 14.5 5.0 13.5 11.3 15.9 S. Em. ± 1.5 2.7	2.5* 10.0 12.5 2.5 3.8 13.8 40.0 42.0 18.5 13.3 15.8 4.3 5.5 3.5 1.5 3.0 22.5 9.5 16.5 18.0 5.8 13.5 14.5 8.0 5.0 13.5 10.5 11.3 15.9 9.6 S. Em. ± C.D. (0.05 %) 1.5 4.4 2.7 7.6 13.1

*Average of four replications

Table 4.16 VAM species composition of Aonla (*Emblica officinalis* Gaertn.) rhizosphere in three different soil types during different sampling period

Date of sampling	Name of fungi		of VAM fungi in of Aonla in	-	Total
		Black soil	Lateritic soil	Red soil	
October, 2003	Glomus I	32	64	16	112
	Glomus II	50	38	10	98
	Acaulospora I	10	36	12	58
	Acaulospora II	10	32	10	52
	Gigaspora white	0	0	0	0
	Sub total	102	170	48	320
December, 2003	Glomus I	8	10	3	21
	Glomus II	9	4	2	15
	Acaulospora I	0	10	1	11
	Acaulospora II	12	13	2	27
	Gigaspora white	0	0	0	0
	Sub total	29	37	8	74
March, 2004	Glomus I	9	8	3	20
	Glomus II	3	0	0	3
	Acaulospora I	0	1	0	1
	Acaulospora II	1	2	0	3
	Gigaspora white	0	0	1	1
	Sub total	13	11	4	28
June, 2004	Glomus I	4	32	16	52
	Glomus II	0	4	0	4
	Acaulospora I	0	12	2	14
	Acaulospora II	1	4	4	9
	Gigaspora white	0	4	0	4
	Sub total	5	56	22	83
August, 2004	Glomus I	16	16	10	42
C ,	Glomus II	16	7	2	25
	Acaulospora I	0	4	0	4
	Acaulospora II	0	5	0	5
	Gigaspora white	0	0	0	0
	Sub total	32	32	12	76
September, 2004	Glomus I	20	16	4	40
	Glomus II	2	8	2	12
	Acaulospora I	4	4	2	10
	Acaulospora II	2	6	0	8
	Gigaspora white	0	0	2	2
	Sub total	28	34	10	72
October, 2004	Glomus I	8	14	10	32
,	Glomus II	2	2	4	8
	Acaulospora I	0	20	4	24
	Acaulospora II	2	0	0	2
	Gigaspora white	0	0	0	0
	Sub total	12	36	18	66
	Grant Total	221	376	122	719

Table 4.17 Soil pH, EC and percent organic content of the soil samples taken from basins of Aonla (varieties NA-7) growing in different soil types

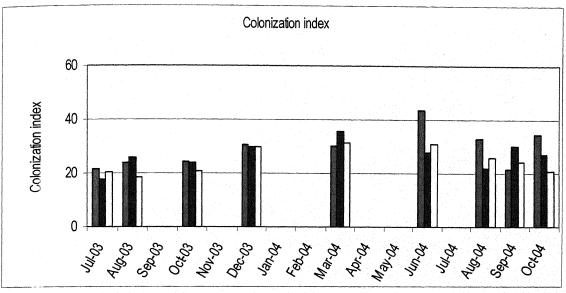
Soil type		pН	EC(μS cm ⁻¹)		% OC
	Mean	Range	Mean	Range	Mean	Range
Black soil	5.88	5.26-6.32	49	28-61	1.53	0.78 - 2.74
Lateritic soil	5.93	5.57-6.44	39	33-49	1.19	0.91 - 1.40
Red soil	5.94	5.75-6.12	38	33-49	1.20	1.09 - 1.42

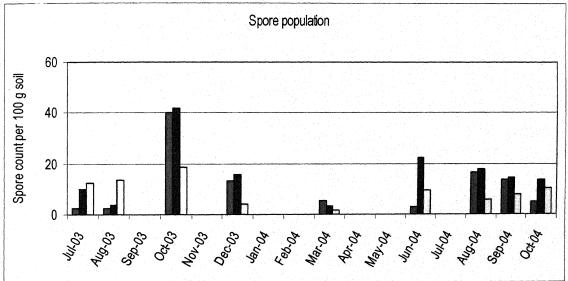
Table 4.18 Colonization index of Aonla roots, soil moisture, soil surface temperature and soil temperature at 10 cm depth in three soil types during summer months

Sampling date	Coloni	zation index of	of Aonla plan	nts in		Soil mo (%		
	Black	Lateritic	Red	Mean	Black	Lateritic	Red	Mean
	soil	soil	soil		soil	soil	soil	
March, 2005	15.2*	29.3	18.3	21.9	-			
	$(23.0)^{\#}$	(32.8)	(25.0)	(26.9)				
April, 2005	17.4	39.1	27.1	27.4	5.6*	4.6	3.9	4.7
•	(24.6)	(38.7)	(31.4)	(31.6)				
May, 2005	19.5	23.4	15.2	19.3	5.0	2.8	2.9	3.6
	(26.2)	(29.0)	(23.0)	(26.1)				
June, 2005	19.7	20.7	25.7	22.0	6.5	7.2	5.6	6.4
•	(26.3)	(27.1)	(30.4)	(28.0)				
Mean	17.9	27.9	21.2		5.7	4.8	4.2	
	(25.0)	(31.9)	(27.5)					
		S. Em.±	C.D.			S. Em.±	C.D.	
			(0.05%)				(0.05%)	
Sampling date		1.4	4.0			0.3	0.9	
Soil type		1.2	3.4			0.3	0.9	
Interaction		2.4	6.9			0.6	NS	
	Soil	temperature a		th		Soil surface to		
A 1 2005	36.0*	37.0	36.3	36.4	51.2*	46.6	41.3	46.4
April, 2005 May, 2005	45.3	46.8	46.8	46.3	73.5	70.2	70.2	71.4
	44.3	44.5	44.3	44.3	60.5	59.9	58.0	59.4
June, 2005 Mean	44.3	42.8	42.4	77.5	61.7	59.0	56.5	
Mean	41.0	S. Em. <u>+</u>	C.D.		01.7	S. Em.±	C.D.	
		5. Liii. <u>-</u>	(0.05%)				(0.05%)	
Commilian data		0.3	1.0			0.3	1.0	
Sampling date		0.3	NS			0.3	1.0	
Soil type Interaction		0.5	NS			0.6	1.7	

^{*} Average of four replications.

[#] Figures in the parenthesis indicate angular transformation values





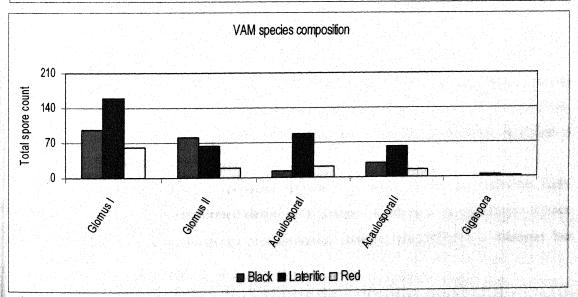


Fig. 4.7 Colonization-index, spore count and species composition of VAM fungi in Aonla variety NA-7 in different soil types during different sampling periods

moisture was recorded during June 2005 (6.4%), followed by April 2005 (4.7%) and May 2005 (3.6%). High values of soil moisture during June 2005 were due to rains just before sampling date. Among different soil types, maximum percent soil moisture was recorded in black soil (5.7%), followed by lateritic soil (4.8%) and red soil (4.2%). Maximum soil temperature at 10 cm depth was recorded during May 2005 (46.3°C), followed by June 2005 (44.3°C) and April 2005 (36.4°C). Differences in sub-soil temperatures were non-significant in different soil types. Maximum soil surface temperature was recorded during May 2005 (71.4°C), followed by June 2005 (59.4°C) and April 2005 (46.4°C). Among three soil types, maximum surface temperature was recorded in black soil (61.7°C), followed by lateritic soil (59.0°C) and red soil (56.5°C).

4.3 <u>Isolation of VAM Fungi, Purification and Multiplication:</u>

Six cultures of *Glomus* species and one culture of *Acaulospora*, were purified form trap cultures set for AM fungi from rhizospheric soil of selected plants of Aonla, Ber, Chironji and Lasoda. Characteristics of isolated were as under:

4.3.1 Acaulospora I: Sporocarp un-known. Spores yellow to light brown under stereo microscope, globose, 108-127 µm in diameter. Remains of sporiferous saccule were seen in some spores. Composite spores wall group 13 µ thick and consisted of four walls in two wall groups (group A & B). Walls group A composed of two layers. Wall 1, yellow (under compound microscope) had ornamentation. Wall 2, an adhering but separable, smooth, hyaline layer. Wall group B composed by wall 3 and wall 4, both hyaline. Spore contents vacuolated. Reaction to meltzer's reagent: outer three spore wall layers yellow, innermost layer quickly belonging deep red on contact. Tentatively identified as Acaulospora scrobiculata.

4.3.2 Glomus 1: Sporocarp present, blackish yellow in reflected light. Chlamydospores formed singly or in clusters in the root, rarely formed outside roots. Chalymydospores predominantly globose (84)-96(125) μ diameter but

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frequently subglobose. Composite spores wall 7.2 μ thick, dark brown under stereo microscope spore with 1 or 2, occasionally up to 4 laminated walls. Walls of the spores extending into the hyphal attachment. Subtanding hyphae is single, (7.2) -11.52-(14.5) μ in diameter at the spore base. The hyphal wall at the point subtending the spore is (2.4)-5.16-(12) μ thick.

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- 4.3.3 Glomus 2: Sporocarp present brownish yellow. Chlamydospores borne singly or in loose clusters in the soil. Globose (36) 49 (72) μ , light yellow under stereo microscope. Spore wall 3.5 μ thick, consist of single wall layer. Spore lighter in colour than the spore wall. Walls of the spores extending into the hyphal attachment and both are same in color. Hypha at the point of spore attachment 8.64 μ wide with 2.4-4.5 μ thick wall, without septum. Pore usually open 1.92 μ in diameter.
- 4.3.4 Glomus 3: Sporocarp present yellow to brown in reflected light. Chlamydospores borne singly or in clusters in the root, rarely formed outside roots, yellow to light brown in under stereo microscope in reflected light, globose to subglobose, $60-124 \times 55-120 \mu$ in diameter with single subtending hyphae. Composite spores wall 4.2 μ thick spores with 1 or 2 laminated walls. Subtending hyphae straight or slightly recurved, septate, (4.8-) 8.7 (-12) μ wide, with walls (1.2-) 2.4 (-2.4) μ thick at the base with a septum, pore diameter (2.4-) 3.7 (-4.8) μ thick.
- 4.3.5 Glomus 4: Sporocarp turmeric yellow in reflected light under stereo microscope. Chlamydospores borne singly or in clusters in the root, brownish yellow in reflected light under stereo microscope, globose to subglobose, 38-115 x 43-103 μ in diameter with single subtending hyphae. Composite spores wall (3.6-) 5.0 (-7.2) μ thick under stereo microscope spore with 1 or 2, laminated walls. Subtending hyphae straight or slightly recurved (9.6-) 10.6 (-12) μ wide, with walls (2.4-) 3.7 (-5.4) μ thick at the spore base, pore 3 μ wide in diameter.

Table 4.19 Characteristics of VAM species isolated from rhizosphere of Aonla, Ber, Chironji and Lasoda

Characters				VAM species			
	Acaulospora 1	Glomus 1	Glomus 2	Glomus 3	Glomus 4	Glomus 5	Glomus 6
Spore Color	Brown	Dark	Light	Yellow to	Brownish	Creamish	Silver
		yellow	yellow	light brown	Yellow	yellow	Shiny
Spore size Mean (µ)	115x115	96x96	49x49	84x81	76x76	59x56	54.2x54
Range (µ)	108-127	84-120x86-125	36-72	60-124x55-120	38-115x43-103	36-96x33-76	48-72x48-67
Composite spore wall	13	7.2	3.5	4.2	5.0	4	2.4
width (µ)	4						
No. of wall groups	2	I		1	Γ	-	_
Muronym	?A(U _o)B(UM)	?A(L)		?A(L)	?A(L)		
Presence of attachment	* •	+	+	+	+	+	+
Presence of hyphal	#		•	1			
terminus							
Wall reaction to	+		•	1	1	•	•
Meltzer's reagent							
Spores formation within		+	-	+	+	+	+
roots							-
Presence of spores in			+	1.	1	ŧ	+
extrametrical hyphae							
Presence of sporocarp	•	+	+	+	+	+	+
Sporocarp color	•	Blackish yellow	Light brownish	Yellow to brown	Yellowish	Creamish yellow	Creamish yellow
			yellow		(turmeric)		
Surface ornamentation	+		•	1	1	1	
* - Absent + Present	ant						

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- **4.3.6** Glomus **5:** Chlamydospore formed in sporocarp and roots. Sporocarp color creemish yellow in reflected light under stereo microscope. Chlamydospore globose to subglobose. Spore diameter average (36-) 59 (-96) x (33-) 56 (-76), spores creamish yellow in reflected light under stereo microscope with 2.5-5 μ thick wall, two wall groups are present and inner wall is dark in color. Subtending hyphae 50 μ long, straight or slightly recorvate, septate, hyline, 5 μ thick at the base of spore.
- 4.3.7 *Glomus* 6: Chlamydospore formed in loose clusters or in sporocarp and rarely in roots. Sporocarp forming outside the root in the month between September to December in pot culture. Sporocarps creamish yellow in reflected light under stereo microscope. Chlamydospore globose, subglobose, silver shiney colored, spore diameter (48-) 54.2 (-72) x (48-) 54(-67) μ , wall upto 2.4 μ thick. Hyphae septate, (4.8-) 7 (-5.6) μ wide at spore base, wall upto 2.8 μ thick. Pore usually opens sometime, closed by a septum, 2.6 μ wide. Color of spore and hypha, walls both are same.

4.4 Screening of VAM Species for Good Plant Growth:

4.4.1 Effect of VAM inoculation on Aonla: Results on effect of inoculation of different VAM species on growth and P uptake of Aonla (*Emblica officinalis* Gaertn.) seedlings are presented in Table 4.20 and Fig. 4.8.

Shoot length: After one month, maximum shoot length was recorded in Glomus 6 (20.7 cm), which was significantly superior to control (13.7 cm). Rest of treatments viz., Glomus 3 (17.2 cm), Glomus 1 (17.0 cm), Acaulospora 1 (15.3 cm), Glomus 5 (14.0 cm), Glomus 4 (13.2 cm) and Glomus 2 (11.8 cm) were at par with control. After two months, shoot length was significantly more in Glomus 1 (59.8 cm), Glomus 3 (57.8 cm) and Acaulospora 1 (55.3 cm) than control (45.7 cm). While all other treatments namely, Glomus 4 (52.5 cm), Glomus 6 (48.5 cm) and Glomus 5 (44.5 cm) were at par with control. Glomus 2 (36.3 cm) was significantly less than control. After three months,

shoot length was significantly more in Glomus 1 (79.0 cm) and Glomus 4 (66.3 cm) than control (51.3 cm). While all other treatments namely, Glomus 3 (64.8 cm), Glomus 5 (60.6 cm), Acaulospora 1 (59.3 cm), Glomus 2 (55.0 cm) and Glomus 6 (52.8 cm) were at par with control. Same trend was observed after four months. Shoot length was significantly more in Glomus 1 (82.7 cm) and Glomus 4 (74.3 cm) than control. While all other treatments namely. Glomus 3 (69.2 cm), Glomus 5 (63.3 cm), Acaulospora 1 (63.3 cm), Glomus 2 (61.0 cm) and Glomus 6 (57.3 cm) were at par with control (56.5 cm). After five months, shoot length was significantly more in Glomus 1 (85.8 cm) than control. While all other treatments viz., Glomus 4 (73.5 cm), Glomus 3 (73.2 cm), Acaulospora 1 (65.0 cm), Glomus 2 (64.2 cm), Glomus 5 (63.5 cm) and Glomus 6 (60.3 cm) were at par with control (59.5 cm). At harvest, shoot length was significantly more in *Glomus* 1 (88.5 cm) and *Glomus* 4 (77.8 cm). While all other treatments namely, Glomus 3 (75.0 cm) Acaulospora 1 (66.7 cm), Glomus 6 (66.0 cm), Glomus 5 (64.3 cm) and Glomus 2 (62.3 cm) were at par with control (62.7 cm).

Collar diameter: After one month, maximum collar diameter was recorded in Glomus 1 (2.4 mm), followed by Acaulospora 1 (2.4 mm), Glomus 6 (2.3 mm), Glomus 2 (2.3 mm), Glomus 4 (2.2 mm), Glomus 3 (2.2 mm) and Glomus 5 (2.0 mm) which were at par with control (2.4 mm). After two months, same trend was recorded in all treatments, which were at par with control. After three months, significantly superior collar diameter were recorded in Glomus 1 (7.0 mm), Glomus 3 (6.6 mm) and Acaulospora 1 (6.2 mm) than control (4.9 mm). While all other treatments namely Glomus 6 (5.7 mm), Glomus 5 (5.5 mm), Glomus 4 (5.2 mm) and Glomus 2 (4.5 mm) were at par with control. Collar diameter after four months was significantly more in Glomus 1 (9.5 mm). While all other treatments viz., Glomus 2 (8.0 mm), Glomus 3 (8.0 mm) Acaulospora 1 (8.0 mm), Glomus 6 (7.9 mm), Glomus 4 (7.6 mm) and Glomus 5 (7.0 mm) were at par with control (7.3 mm). After five months, collar diameter was significantly more Glomus 1 (10.8 mm.),

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while all treatments namely, *Glomus* 3 (9.0 mm), *Acaulospora* 1 (9.0 mm) *Glomus* 2 (8.8 mm), *Glomus* 4 (8.8 mm), *Glomus* 6 (8.7 mm) and *Glomus* 5 (7.5 mm) were at par with control (8.0 mm). At harvest, significantly superior collar diameter was recorded in *Glomus* 1 (11.4 mm). While other treatments namely *Glomus* 3 (9.6 mm), *Acaulospora* 1 (9.6 mm), *Glomus* 4 (9.5 mm), *Glomus* 2 (9.4 mm), *Glomus* 6 (9.4 mm) and *Glomus* 5 (8.1 mm) were at par with control (8.5 mm).

Fresh weight: At harvest, maximum fresh weight of the shoot was recorded in Glomus 1 (36.88 g), followed by Glomus 6 (31.96 g), Glomus 4 (30.93 g) and Glomus 3 (27.80 g) which were significantly more than control (19.02 g). Acaulospora 1(24.58 g), Glomus 5 (20.62 g) and Glomus 2 (17.30 cm) were at par with control. Fresh weight of root was recorded in Glomus 1 (86.08 g), Glomus 6 (78.14 g), Acaulospora 1 (76.80 g), Glomus 3 (74.11 g), Glomus 4 (69.59 g) and Glomus 5 (67.51 g) were at par with control (70.78 g). Glomus 2 (48.33 g) was the poorest and significantly less than control.

Dry weight: At harvest maximum dry weight of the shoot was recorded in Glomus 1 (17.58 g), followed by Glomus 4 (15.08 g), Acaulospora 1 (14.37 g), Glomus 3 (13.34 g) and Glomus 6 (12.67 g) which were significantly more than control (9.56 g). While Glomus 5 (9.63 g) was at par with control. Glomus 2 (6.43 g) was significantly less than control. At harvest, maximum dry weight of the root was recorded in Glomus 1 (29.55 g), followed by Glomus 6 (26.53 g), Acaulospora 1 (26.43 g) and Glomus 3 (25.23 g), which were significantly more than control (20.53 g). Glomus 4 (23.69 g) and Glomus 5 (22.36 g) were at par with control. Glomus 2 (15.43 g) was less than control.

Phosphorus: Maximum phosphorus uptake per plant was recorded in *Glomus* 3 (97.197 mg), followed by *Acaulospora* 1 (72.383 mg) and *Glomus* 6 (57.977 mg) which were significantly superior to control. *Glomus* 4 (55.000 mg), *Glomus* 1 (51.380 mg) and *Glomus* 5 (40.657 mg) were at par with control (47.423 mg). *Glomus* 2 (28.277 mg) was significantly less than control.

Table 4.20 Effect of inoculation of different VAM species on growth and P uptake of Aonla (Emblica officinalis Gaertn.) seedlings

VAM cultures			Shoot length after	th after				Ŭ	Collar diameter after	neter afte	.		Fresh w	weight	Dry we	sight	Ъ
			(cm)						(mm)	(r			(g)	_	(g)		uptake
	One	Two	Three	Four	Five	At	One	Two	Three	Four	Five	At	Shoot	Root	Shoot	Root	per
	month	month	month	month	month	harvest	month	month	month	month	month	harvest					plant
																	(mg)
Acaulospora 1	15.3	55.3	59.3	63.3	65.0	2.99	2.4	4.6	6.2	8.0	0.6	9.6	24.58	76.80	14.37	26.43	72.383
Glomus 1	17.0	29.8	79.0	82.7	82.8	88.5	2.4	5.3	7.0	9.5	10.8	11.4	36.88	80.98	17.58	29.55	51.380
Glomus 2	11.8	36.3	55.0	61.0	64.2	62.3	2.3	4.0	4.5	8.0	8.8	9.4	17.30	48.33	6.43	15.43	28.277
Glomus 3	17.2	57.8	64.8	69.2	73.2	75.0	2.2	5.1	9.9	8.0	9.0	9.6	27.80	74.11	13.34	25.23	97.197
Glomus 4	13.2	52.5	66.3	74.3	73.5	77.8	2.2	4.0	5.2	9.7	8.8	9.5	30.93	69.59	15.08	23.69	55.000
Glomus 5	14.0	44.5	9.09	63.3	63.5	64.3	2.0	4.2	5.5	7.0	7.5	8.1	20.62	67.51	9.63	22.36	40.657
Glomus 6	20.7	48.5	52.8	57.3	60.3	0.99	2.3	5.2	5.7	7.9	8.7	9.4	31.96	78.14	12.67	26.53	57.977
Control	13.7	45.7	51.3	56.5	59.5	62.7	2.4	4.5	4.9	7.3	8.0	8.5	19.02	70.78	9.56	20.53	47.423
S. Em.±	1.7	2.6	5.0	4.9	5.0	5.0	0.2	0.3	0.3	0.5	1.7	0.7	2.0	3.7	8.0	1.5	3.296
C.D. (0.05%)	4.9	7.9	15.0	14.6	15.1	14.9	0.5	6.0	8.0	1.6	4.9	2.0	0.9	11.1	2.5	4.4	088.6

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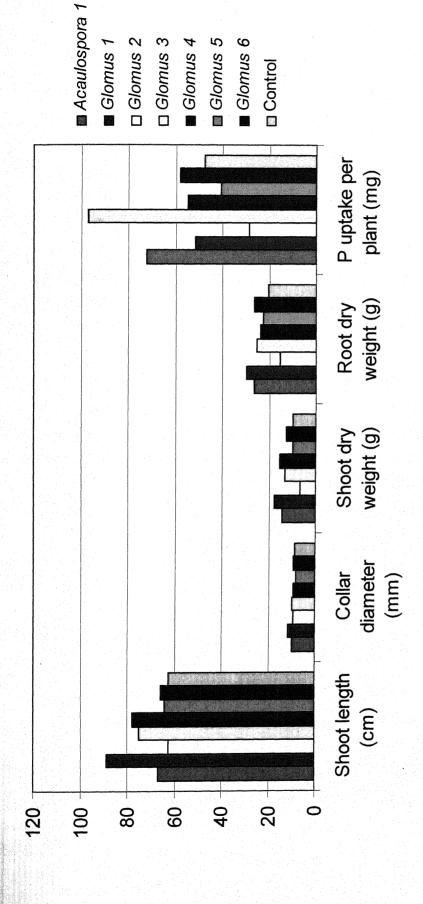


Fig. 4.8 Effect of VAM inoculations on growth and P uptake of Aonla (Emblica officinalis Gaertn.) seedlings

In short, Glomus 1 and Glomus 4 significantly increased shoot length of Aonla, Glomus 1 significantly increased collar diameter, Glomus 1, Glomus 6, Glomus 4 and Glomus 3 significantly increased fresh shoot weight, Glomus 1, Glomus 4, Acaulospora 1, Glomus 3 and Glomus 6 significantly increased dry shoot weight and Glomus 1, Glomus 6, Acaulospora 1, and Glomus 3 significantly increased dry root weight. Glomus 3, Acaulospora 1 and Glomus 6 significantly increased P uptake per plant. Rests of treatments were found ineffective.

4.4.2 Effect of VAM inoculation on Ber: Results on effect of inoculation of different VAM species on growth and P uptake of Ber (*Zizyphus mauritiana* Lamk.) seedlings are presented in Table 4.21 and Fig. 4.9.

Shoot length: After one month, maximum shoot length was recorded in Glomus 4 (15.3 cm), which was significantly superior to control (11.5 cm). Glomus 3 (14.5 cm), Acaulospora 1 (14.5 cm), Glomus 1 (12.8 cm), Glomus 5 (12.3 cm), Glomus 2 (11.7 cm) and Glomus 6 (11.3 cm) were at par with control. After two months, shoot length was significantly more in Glomus 3 (49.8 cm) and Glomus 4 (47.8 mm) than control (36.8 cm). Glomus 1 (43.7 cm), Glomus 6 (42.3 cm), Acaulospora 1 (35 cm) and Glomus 5 (33.8 cm) were at par with control. Glomus 2 (27.3 cm) was significantly less than control. After three months, shoot length in Glomus 3 (68.0 cm), Glomus 1 (65.7 cm), Glomus 4 (63.0 cm), Glomus 6 (59.7 cm) and Acaulospora 1 (57.5 cm) were at par with control (61.0 cm). Glomus 5 (51.0 cm) and Glomus 2 (42.0 cm) were significantly less than control. After four months, maximum shoot length was recorded in Glomus 1 (91.2 cm), which was significantly more than control (77.5 cm). Glomus 3 (84.8 cm), Glomus 4 (80.0 cm), Glomus 6 (79.3 cm), Glomus 5 (75.2 cm) and Acaulospora 1 (67.5 cm) were at par with control. Glomus 2 (55.7 cm) was significantly less than control. After five months, Glomus 1 (97.2 cm), Glomus 3 (91.7 cm), Glomus 6 (87.3 cm), Glomus 4 (85.8 cm) and Glomus 5 (79.0 cm) were at par with control (89.3 cm). Acaulospora 1 (74.8 cm) and Glomus 2 (64.2 cm) were significantly less

than control. At harvest, *Glomus* 1 (104.3), *Glomus* 3 (94.2), *Glomus* 6 (92.3), *Glomus* 4 (89.0) and *Glomus* 5 (82.3) were at par with control (92.8). *Acaulospora* 1 (79.0 cm) and *Glomus* 2 (66.5 cm) were significantly less than control.

Collar diameter: After one month, maximum collar diameter was recorded in Glomus 3 (3.1 mm), which was significantly more than control (2.5 mm). Glomus 6 (2.9 mm), Glomus 4 (2.7 mm), Glomus 2 (2.7 mm), Glomus 1 (2.5 mm), Glomus 5 (2.4 mm) and Acaulospora 1 (2.4 mm) were at par with control. After two months, collar diameter was significantly more in Glomus 4 (4.7 mm), Glomus 1 (4.2 mm), Glomus 6 (4.1 mm) and Glomus 5 (4.1 mm) than control (3.5 mm). Glomus 3 (4.0 mm) Acaulospora 1 (3.6 mm) and Glomus 2 (3.1 mm) were at par with control. After three months, collar diameter was significantly more in Glomus 1 (7.8 mm) and Glomus 3 (7.2 mm) than control (5.7 mm). Glomus 4 (6.7 mm), Glomus 6 (6.3 mm), Glomus 5 (6.1 mm), Acaulospora 1 (5.8 mm) and Glomus 2 (5.2 mm) were at par with control. After four months, maximum collar diameter was recorded in Glomus 1 (8.3 mm). Glomus 3 (7.8 mm), Glomus 4 (7.6 mm), Glomus 5 (6.9 mm) and Glomus 6 (6.7 mm) were at par with control (8.1 mm). Glomus 2 (6.5 mm) and Acaulospora 1 (6.4 mm) were significantly less than control. After five months, maximum collar diameter was recorded in Glomus 1 (8.9 mm). Glomus 3 (8.7 mm), Glomus 4 (8.0 mm), Glomus 5 (7.5 mm), Glomus 6 (7.3 mm) and Acaulospora 1 (7.0 mm) were at par with control (8.5 mm). Glomus 2 (6.0 mm) was significantly less than control. At harvest, all treatments viz., Glomus 1 (9.8 mm), Glomus 3 (9.4 mm), Glomus 6 (9.3 mm), Glomus 4 (8.5 mm), Glomus 5 (7.9 mm), Acaulospora 1 (7.4 mm) and Glomus 2 (7.3 mm) were at par with control (9.0 mm).

Fresh weight: At harvest, significantly superior fresh weight of the shoot was recorded in Glomus 1 (48.07 g) and Glomus 6 (38.78 g). Glomus 3 (35.86 g), Glomus 4 (35.18 g) and Glomus 5 (25.93 g) were at par with control (31.38 g). Acaulospora 1 (24.76 g) and Glomus 2 (17.62 cm) were significantly less than

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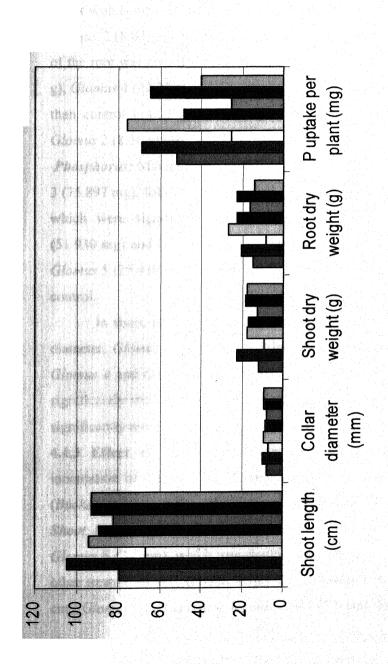
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Table 4.21 Effect of inoculation of different VAM species on growth and P uptake of Ber (Zizyphus mauritiana Lamk.) seedlings

m m							٠						I WOLKIIL			4
m ra 1		5)	(cm)					(mm)	m)			(S)		, 9)	, _	uptake
п ra 1	Two	Three	Four	Five	At	One	Two	Three	Four	Five	At	Shoot	Root	Shoot	Root	per
ra 1	month	month	month	month	harvest	month	month	month	month	month	harvest					plant
ra 1						-										(mg)
	35.0	57.5	67.5	74.8	79.0	2.4	3.6	5.8	6.4	7.0	7.4	24.76	32.82	11.68	14.58	51.930
	43.7	65.7	91.2	97.2	104.3	2.5	4.2	7.8	8.3	8.9	8.6	48.07	48.59	22.73	20.58	68.507
Glomus 2 11.5	27.3	45.0	55.7	64.2	66.5	2.7	3.1	5.2	6.5	6.4	7.3	17.62	17.72	8.84	8.26	25.170
	49.8	0.89	84.8	91.7	94.2	3.1	4.0	7.2	7.8	8.7	9.4	35.86	62.42	17.46	26.75	75.897
	47.8	63.0	80.0	82.8	89.0	2.7	4.7	6.7	9.7	8.0	8.5	35.18	59.43	17.14	22.37	48.223
	33.8	51.0	75.2	79.0	82.3	2.4	4.1	6.1	6.9	7.5	7.9	25.93	41.44	12.62	16.39	25.410
	42.3	59.7	79.3	87.3	92.3	5.9	4.1	6.3	6.7	7.3	9.3	38.78	57.90	18.38	22.78	64.537
	36.8	61.0	77.5	89.3	8.76	2.5	3.5	5.7	8.1	8.5	0.6	31.38	30.45	17.15	14.03	40.01
S. Em.± 1.14	3.13	3.14	4.29	4.29	4.34	0.14	0.17	0.40	0.46	0.54	0.64	2.05	5.21	1.16	2.10	4.067
C.D. (0.05%) 3.43	9.38	9.40	12.85	12.85	13.02	0.43	0.52	1.20	1.38	1.62	1.94	6.15	15.63	3.48	6.30	12.192

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■ Glomus 5

■ Glomus 4

■ Glomus 6

■ Control

■ Acaulos pora 1

□ Glomus 2

☐ Glomus 3

Glomus 1

Fig. 4.9 Effect of VAM inoculations on growth and P uptake of Ber (Zizyphus mauritiana Lamk.) seedlings

control. Significantly superior fresh weight of root was recorded in *Glomus* 3 (62.42 g) followed by, *Glomus* 4 (59.43 g) and *Glomus* 6 (57.90 g). While *Glomus* 1 (48.59 g), *Glomus* 5 (41.44 g), *Acaulospora* 1 (32.82 g) and *Glomus* 2 (17.72 g) were at par with control (30.46).

Dry weight: Dry weight of the shoot was significantly more in Glomus 1 (22.73 g). Glomus 6 (18.38 g), Glomus 3 (17.46 g), Glomus 4 (17.14 g) were at par with control (17.150). Glomus 5 (12.62 g), Acaulospora 1 (11.68 g) and Glomus 2 (8.84 g) were significantly less than control. Maximum dry weight of the root was recorded in Glomus 3 (26.75 g), followed by Glomus 6 (22.78 g), Glomus 4 (22.37 g) and Glomus 1 (20.58 g), which were significantly more than control (14.03 g). Glomus 5 (16.39 g), Acaulospora 1 (14.59 g) and Glomus 2 (8.26 g) were at par with control.

Phosphorus: Maximum phosphorus uptake per plant was recorded in *Glomus* 3 (75.897 mg), followed by *Glomus* 1 (68.507 mg) and *Glomus* 6 (64.537 mg), which were significantly more than control (40.01 mg). *Acaulospora* 1 (51.930 mg) and *Glomus* 4 (48.223 mg) were at par with control (40.01 mg). *Glomus* 5 (25.410 mg) and *Glomus* 2 (25.170 mg) were significantly less than control.

In short, none of tested VAM fungi increased shoot length and collar diameter, *Glomus* 1 and *Glomus* 5 increased fresh shoot weight, *Glomus* 3, *Glomus* 4 and *Glomus* 2 significantly increased dry shoot weight, *Glomus* 3 significantly increased dry root weight and phosphorus uptake per plant was significantly more in *Glomus* 3, *Glomus* 1 and *Glomus* 6.

4.4.3 Effect of VAM inoculation on Chironji: Results on effect of inoculation of different VAM species on growth and P uptake of Chironji (Buchanania lanzan Spr.) seedlings are presented in Table 4.22 and Fig. 4.10. Shoot length: After one month, maximum shoot length was recorded in Glomus 6 (7.2 cm), which was significantly superior to control (5.5 cm). All other treatments viz., Glomus 4 (6.3 cm), Glomus 1 (6.2 cm), Glomus 5 (5.7 cm), Glomus 2 (5.3 cm) and Acaulospora 1 (5.0 cm) were at par with control.

Glomus 3 (3.3 cm) was significantly less than control. After two months, shoot length was significantly more in Glomus 4 (9.8 cm) and Glomus 6 (9.7 cm) than control (6.0 cm). Glomus 1 (7.2 cm), Glomus 5 (7.0 cm), Acaulospora 1(6.8 cm), Glomus 2 (6.5 cm) and Glomus 3 (6.2 cm) were at par with control. After three months, shoot length was significantly more in Glomus 6 (12.5 cm), Glomus 4 (12.5 cm), Glomus 1 (12.0 cm) and Glomus 3 (10.5 cm) than control (7.0 cm). Glomus 5 (8.2 cm), Acaulospora 1(8.0 cm) and Glomus 2 (7.0 cm) were at par with control. After four months, shoot length, was significantly more in Glomus 6 (17.8 cm) and Glomus 4 (17.2 cm) than control (8.5 cm). All other treatments viz., Glomus 1 (14.67 cm), Glomus 3 (13.57 cm), Acaulospora 1 (10.83 cm), Glomus 5 (10.67 cm) and Glomus 2 (7.5 cm) were at par with control. After five months, shoot length was significantly more in Glomus 4 (22.7 cm) and Glomus 6 (19.7 cm) than control (10.3 cm). Glomus 1 (17.3 cm), Glomus 3 (15.7 cm), Acaulospora 1 (12.0 cm), Glomus 5 (11.3 cm) and Glomus 2 (7.7 cm) were at par with control. At harvest, shoot length was significantly more in Glomus 4 (23.2 cm), Glomus 6 (19.8 cm), Glomus 1 (18.5 cm), Glomus 3 (16.7 cm) and Glomus 5 (13.5 cm) than control (10.3 cm). Acaulospora 1 (13.0 cm) and Glomus 2 (8.8 cm) were at par with control.

Collar diameter: After one month, collar diameter in Glomus 3 (4.0 mm) was significantly more than control (2.8 mm). Acaulospora 1 (3.1 mm), Glomus 4 (3.1 mm), Glomus 2 (3.0 mm), Glomus 1 (2.7 mm), Glomus 5 (2.5 mm) and Glomus 6 (2.5 mm) were at par with control. After two months, all treatments namely, Glomus 4 (3.8 mm), Acaulospora 1 (3.5 mm), Glomus 6 (3.4 mm), Glomus 5 (3.1 mm), Glomus 1 (3.1 mm), Glomus 2 (3.0 mm) and Glomus 3 (3.0 mm) were at par with control (3.5 mm). After three months, collar diameter was significantly more in Glomus 4 (5.1 mm) Glomus 1 (4.9 mm), Glomus 6 (4.3 mm), Acaulospora 1 (4.3 mm) and Glomus 3 (4.2 mm) than control (3.0 mm). While other treatments viz., Glomus 5 (3.8 mm) and Glomus 2 (3.7 mm) were at par with control. After four months, collar diameter was

significantly more in *Glomus* 4 (6.7 mm), *Glomus* 1 (5.9 mm), *Glomus* 6 (5.2 mm), *Acaulospora* 1 (4.8 mm) and *Glomus* 3 (4.6 mm) than control (3.3 mm). *Glomus* 5 (4.1 mm) and *Glomus* 2 (4.0 mm) were at par with control. After five months, collar diameter was significantly more in *Glomus* 4 (7.1 mm), *Glomus* 6 (6.4 mm), *Glomus* 1 (6.2 mm), *Acaulospora* 1 (5.3 mm), *Glomus* 3 (4.9 mm) and *Glomus* 5 (4.8 mm) than control (3.5 mm). *Glomus* 2 (4.3 mm) was at par with control. At harvest, collar diameter was significantly more in *Glomus* 4 (7.5 mm), *Glomus* 6 (7.0 mm), *Glomus* 1 (6.4 mm), *Acaulospora* 1 (5.5 mm), *Glomus* 5 (5.3 mm) and *Glomus* 3 (5.2 mm) than control (3.9 mm). *Glomus* 2 (4.4 mm) was at par with control.

Fresh weight: At harvest, fresh weight of the shoot was significantly more in Glomus 6 (20.95 g), Glomus 4 (20.56 g), Glomus 1 (14.69 g) and Glomus 3 (9.98 g) than control (4.6 g). Acaulospora 1 (8.27 g), Glomus 5 (6.71 g) and Glomus 2 (4.28 cm) were at par with control. Fresh weight of the root was significantly more in Glomus 4 (23.78 g), Glomus 6 (20.97 g), Glomus 1 (17.83 g) and Glomus 3 (14.99 g) than control (6.67 g). Acaulospora 1 (11.19 g), Glomus 2 (10.22 g) and Glomus 5 (8.66 g) were at par with control.

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Dry weight: At harvest, dry weight of the shoot was significantly more in Glomus 4 (7.74 g), Glomus 6 (7.10 g), Glomus 1 (4.98 g) and Glomus 3 (4.05 g) than control (1.9 g). Acaulospora 1 (2.88 g), Glomus 5 (2.80 g) and Glomus 2 (1.84 g) were at par with control. Dry weight of the root was significantly more in Glomus 4 (8.64 g), Glomus 6 (7.06 g), Glomus 3 (4.76 g) and Glomus 1 (4.61 g) than control (2.4 g). Acaulospora 1 (3.56 g), Glomus 2 (3.56) and Glomus 5 (3.10 g), were at par with control.

Phosphorus: Phosphorus uptake per plant was significantly more in *Glomus* 6 (22.487 mg) *Glomus* 1 (15.733 mg), *Acaulospora* 1 (15.570 mg) and *Glomus* 4 (12.857 mg) than control (7.857 mg). *Glomus* 3 (9.437 mg), *Glomus* 2 (6.683 mg) and *Glomus* 5 (6.073 mg) were at par with control.

In general, among tested VAM species Glomus 4 was found more effective in increasing biomass of Chironji in terms of shoot length, collar

Table 4.22 Effect of inoculation of different VAM species on growth and P uptake of Chironjii (Buchanania lanzan Spr.) seedlings

Sho	Sho	Sho	oot lei	hoot length after				O	Collar diameter	ameter after	7.		Fresh weight	veight	Dry weight	eight	P
n)	n)	n)	n)							(III)			(Ĕ	_	9	1	uprano
One Two Three Four Five A	Three Four Five	Four Five	Four Five		∀	ړېد	One	Two	Three	Four	Five	At	Shoot	Root	Shoot	Root	ber
month month h	month month month h	month month month h	month month h		ha	arvest	month	month	month	month	month	harvest					plant (mg)
	8.0 10.8			12.0		13.0	3.1	3.5	4.3	4.8	5.3	5.5	8.27	11.19	2.88	3.56	15.570
12.0 14.7	12.0 14.7	14.7		17.3		18.5	2.7	3.1	4.9	5.9	6.2	6.4	14.69	17.83	4.98	4.61	15.733
6.5 7.0 7.5	7.0 7.5	7.5		7.7		8.8	3.0	3.0	3.7	4.0	4.3	4.4	4.28	10.22	1.84	3.56	6.683
6.2 10.5 13.6	10.5 13.6	13.6		15.7		16.7	4.0	3.0	4.2	4.6	4.9	5.2	10.00	14.99	4.05	4.76	9.437
9.8 12.5 17.2	12.5 17.2	17.2		22.7		23.2	3.1	3.8	5.1	6.7	7.1	7.5	20.56	23.78	7.74	8.64	12.857
7.0 8.2 10.7	8.2 10.7	10.7		11.3		13.5	2.5	3.1	3.8	4.1	4.8	5.3	6.71	99.8	2.80	3.10	6.073
7.2 9.7 12.5 17.8 19.7	12.5 17.8	17.8		19.7		19.8	2.5	3.4	4.3	5.2	6.4	7.0	21.00	20.97	7.10	7.06	22.487
6.0 7.0 8.5	7.0 8.5	8.5		10.3		10.3	2.8	3.5	3.0	3.3	3.5	3.9	4.61	. 89.9	1.91	2.42	7.857
0.47 0.79 1.06 2.26 2.78	1.06 2.26	2.26		2.78		1.04	0.27	0.26	0.42	0.34	0.31	1.24	3.82	2.44	0.74	0.56	1.343
1.4 2.4 3.2 6.8 8.4				8.4		3.1	8.0	8.0	1.2	1.0	6.0	1.2	3.8	7.3	1.5	1.7	4.026

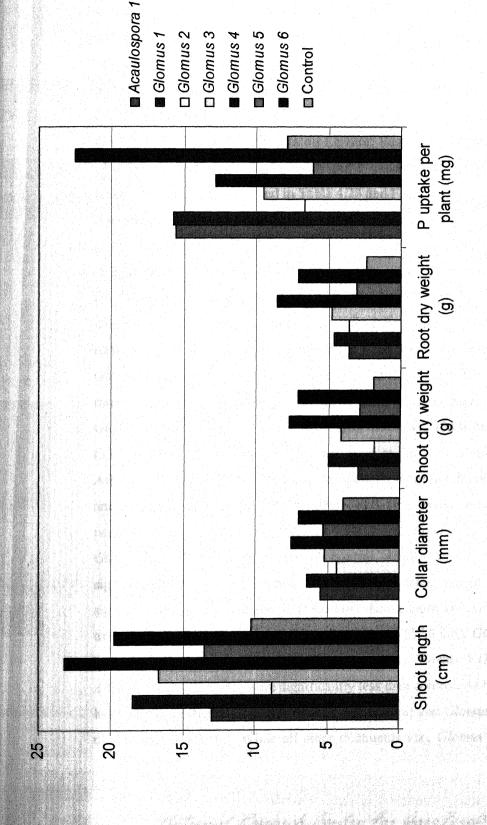


Fig. 4.10 Effect of VAM inoculation on growth and P uptake of Chironji (Buchanania lanzan Spr.) seedlings

diameter, fresh and dry weight of shoot and root, *Glomus* 6, *Glomus* 1 and *Glomus* 3 also increased the shoot length, fresh and dry biomass of the tree species. *Acaulospora* 1 and *Glomus* 5 significantly increased collar diameter but these treatments were at par with control with respect to other tested parameters. *Glomus* 2 decreased the growth of Chironji, however the differences were not significant.

4.4.4 Effect of VAM inoculation on Lasoda: Results on effect of inoculation of different VAM species on growth and P uptake of Lasoda (*Cordia myxa* Roxb.) seedlings are presented in Table 4.23 and Fig. 4.11.

Shoot length: After one month, shoot length in Glomus 6 (11.7 cm), Glomus 5 (10.7 cm), Glomus 4 (10.7 cm), Glomus 2 (10.2 cm), Glomus 3 (10.2 cm), Acaulospora 1 (10.0 cm) and Glomus 1 (9.2 cm) was at par with control (10.3 cm). After two months, shoot length was significantly more in Glomus 6 (30.0 cm) and Glomus 4 (29.3 cm) than control (25.2 cm). While all other treatments namely, Glomus 1 (27.3 cm), Acaulospora 1 (26.3 cm), Glomus 5 (26.0 cm), Glomus 3 (25.8 cm) and Glomus 2 (24.0 cm) were at par with control. After three months, shoot length in Glomus 4 (37.0 cm), Glomus 5 (36.8 cm), Glomus 1 (34.5 cm), Glomus 6 (33.7 cm), Glomus 2 (33.0 cm), Glomus 3 (33.0 cm) and Acaulospora 1 (29.5 cm) were at par with control (33.3 cm). After four months, shoot length was significantly more in Glomus 4 (47.7 cm) and Glomus 6 (47.0 cm) than control (40.0 cm). While other treatments namely, Glomus 5 (45.2 cm), Glomus 1 (40.7 cm), Glomus 3 (38.0 cm) and Glomus 2 (37.0 cm) were at par with control. Acaulospora 1 (30.7 cm) was significantly less than control. After five months, shoot length was significantly more in Glomus 4 (59.0 cm) than control (47.3). While other treatments namely, Glomus 5 (57.0 cm), Glomus 6 (57.8 cm), Glomus 1 (49.0 cm) Glomus 2 (43.3 cm) were at par with control. Glomus 3 (36.8 cm) and Acaulospora 1 (32.0 cm) were significantly less than control. At harvest, shoot length was significantly more in Glomus 4 (60.2 cm) and Glomus 5 (57.8 cm) than control (47.3 cm). While all other treatments viz., Glomus 1 (53.7 cm),

Glomus 6 (51.9 cm), Glomus 2 (45.5 cm) and Glomus 3 (38.5 cm) were at par with control. Acaulospora 1 (34.8 cm) was significantly less than control.

Collar diameter: After one month, collar diameter in Glomus 2 (4.6 mm), Glomus 5 (4.3 mm), Glomus 6 (4.3 mm), Glomus 4 (4.1 mm), Acaulospora 1 (4.1mm), Glomus 3 (4.0 mm) and Glomus 1 (3.6 mm) was at par with control (3.7 mm). After two months, Glomus 4 (8.2 mm), Glomus 1 (8.0 mm), Glomus 6 (7.8 mm), Acaulospora 1 (7.6 mm), Glomus 5 (7.5 mm) and Glomus 2 (7.2 mm) were at par with control. Glomus 3 (6.8 mm) was significantly less than control. After three months, collar diameter was significantly more in Glomus 6 (14.2 mm) and Glomus 4 (12.4 mm) than control (11.0 mm). Glomus 5 (11.8 mm), Glomus 2 (11.7 mm), Glomus 3 (11.6 mm), Acaulospora 1 (10.6 mm) and Glomus 1 (10.5 mm) were at par with control. After four months, collar diameter was significantly more in Glomus 6 (17.0 mm), Glomus 3 (15.2 mm), Glomus 2 (14.8 mm) and Glomus 4 (14.3 mm) than control (12.0 mm). While other treatments namely, Glomus 5 (14.0 mm), Glomus 1 (13.8 mm), and Acaulospora 1 (12.6 mm) were at par with control. After five months, collar diameter was significantly more in Glomus 6 (17.5 mm) and Glomus 5 (16.9 mm) than control (14.9 mm). While other treatments viz., Glomus 2 (16.4 mm), Glomus 4 (16.3 mm), Glomus 3 (16.2 mm), Acaulospora 1 (16.0 mm) and Glomus 1 (15.5 mm) were at par with control. At harvest, collar diameter in all treatments viz., Glomus 2 (18.8 mm), Glomus 6 (18.3 mm), Glomus 3 (18.1 mm), Glomus 4 (17.7 mm), Glomus 1 (17.5 mm), Glomus 5 (17.5 mm) and Acaulospora 1 (17.5 mm) was at par with control (7.3 mm).

Fresh weight: At harvest, fresh weight of the shoot was significantly more in Glomus 4 (64.35 g), Glomus 5 (62.79 g), Glomus 1 (58.60 g) than control (50.5 cm). Glomus 6 (52.66 g) and Glomus 2 (50.37 cm) were at par with control. Glomus 3 (43.60 cm) and Acaulospora 1 (38.38 g) were significantly less than control. Fresh weight of root was significantly more in Glomus 2 (106.06 g) and Glomus 4 (100.09 g) than control (81.12 g). While other

Table 4.23 Effect of inoculation of different VAM species on growth and P uptake of Lasoda (Cordia myxa Roxb.) seedlings

And the second s																	
VAM cultures		S	noot lengt	Shoot length (cm) after	ter			Coll	Collar diameter (mm) after	er (mm)	after		Fresh weight	weight	Dry weight	eight	Ь
													3)	(5	<u>a</u>		uptake
	One	Two	Three	Four	Five	At	One	Two	Three	Four	Five	At	Shoot	Root	Shoot	Root	ber
	month	month	month	month	month	harvest	month	month	month	month	month	harvest					plant
																	(mg)
lcaulospora 1	10.0	26.3	29.5	30.7	32.0	34.8	4.1	9.7	10.6	12.6	16.0	17.5	38.38	88.08	12.23	26.62	80.557
nus 1	9.5	27.3	34.5	40.7	49.0	53.7	3.6	8.0	10.5	13.8	15.5	17.5	58.60	96.34	21.10	33.40	110.767
nus 2	10.2	24.0	33.0	37.0	43.3	45.5	4.6	7.2	11.7	14.8	16.4	18.8	50.37	106.06	19.60	34.99	86.423
nus 3	10.2	25.8	33.0	38.0	36.8	38.5	4.0	8.9	11.6	15.2	16.2	18.1	43.60	92.92	14.83	34.41	84.143
nus 4	10.7	29.3	37.0	47.7	59.0	60.2	4.1	8.2	12.4	14.3	16.3	17.7	64.35	100.09	23.82	33.81	80.703
Glomus 5	6.6	26.0	36.8	45.2	57.0	57.8	4.3	7.5	11.8	14.0	16.9	17.5	62.79	93.52	22.75	31.34	82.943
nns 6	11.7	30.0	33.7	47.0	51.8	51.9	4.3	7.8	14.2	17.0	17.5	18.3	52.66	85.87	20.25	29.08	78.137
Control	10.3	25.2	33.3	40.0	47.3	47.3	3.9	8.5	11.0	12.0	14.9	17.1	50.50	81.12	19.61	27.62	56.043
3. Em.±	0.88	1.23	1.45	2.1	3.46	3.44	0.31	0.45	0.75	69.0	0.55	0.72	9.6	5.51	1.36	1.36	6.544
C.D. (0.05%)	2.64	3.68	4.31	6.29	10.38	10.32	0.94	1.35	2.24	2.1	1.66	2.16	3.20	16.52	4.09	4.1	19.617
													-				

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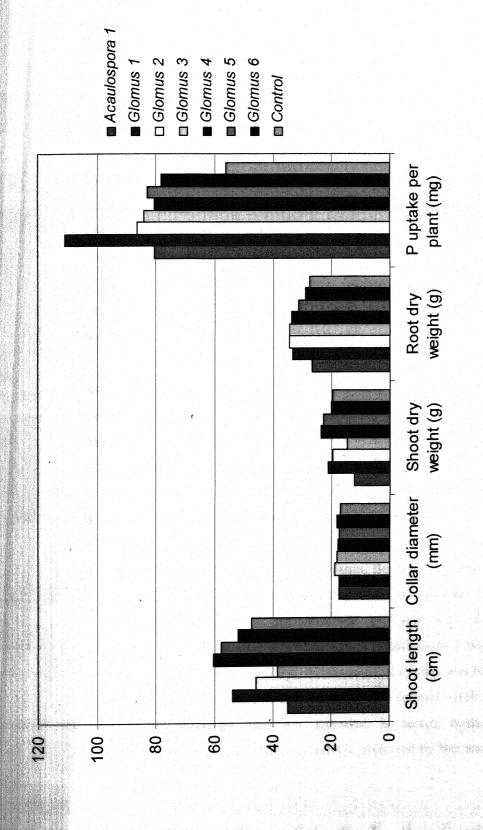


Fig. 4.11 Effect of VAM inoculation on growth and P uptake of Lasoda (Cordia myxa Roxb.) seedlings

treatments viz., Glomus 1 (96.34 g), Glomus 3 (92.92 g), Glomus 5 (93.52 g), Glomus 6 (85.87 g) and Acaulospora 1 (80.88 g) were at par with control.

Dry weight: At harvest, no significant difference was recorded in dry weight of the shoot. Glomus 4 (23.82 g), Glomus 5 (22.75 g), Glomus 1 (21.10 g), Glomus 6 (20.25 g) and Glomus 2 (19.60 g) were at par with control (19.61). Glomus 3 (14.83 g) and Acaulospora 1 (12.23 g) were significantly less than control. Dry weight of the root was significantly superior in Glomus 2 (34.99 g), Glomus 3 (34.41 g), Glomus 4 (33.81 g) and Glomus 1 (33.40 g) than control (27.62 g). Glomus 5 (31.34 g), Glomus 6 (29.08 g) and Acaulospora 1 (26.62 g) were at par with control.

Phosphorus: Phosphorus uptake per plant was significantly more in *Glomus* 1 (110.767 mg), *Glomus* 2 (86.423 mg), *Glomus* 3 (84.143 mg), *Glomus* 5 (82.943 mg), *Glomus* 4 (80.703 mg), *Acaulospora* 1 (80.557 mg) and *Glomus* 6 (78.737) than control (56.043).

In general, Glomus 4 and Glomus 5 significantly increased shoot length of Lasoda. No treatment significantly increased collar diameter. Glomus 4, Glomus 5 and Glomus 1 significantly increased fresh shoot weight. No significant difference among treatments were recorded in dry shoot weight, Glomus 2 and Glomus 4 significantly increased fresh root weight, Glomus 2, Glomus 3, Glomus 4 and Glomus 1 significantly increased dry root weight and all the treatments significantly increased P uptake per plant.

4.5 Build up of VAM Colonization in Aonla, Ber and Chironji:

Data on colonization of Aonla, Ber and Chironji after 2, 3, 4 and 5 months by *Acaulospora* 1 are presented in Table 4.24. Formation of arbuscules and vesicles after inoculation with *Acaulospora* 1 was poor in all tested combinations. Good amount of extrametrical hyphae was recorded in all treatments. Spores in extrametrical hyphae, spores formed within the root and presence of sporocarp was not recorded in tested hosts. Maximum colonization index was recorded in Chironji, followed by Ber and Aonla. The

index values were quite low. Spore population per 100 g in rhizosphere of Ber and Aonla were very high as compared to Chironji.

Data on colonization of Aonla, Ber and Chironji by *Glomus* 1 are presented in Table 4.25. Formation of arbuscules was poor in Ber and Chironji and absent in Aonla. Formation of vesicles and extrametrical hyphae was excellent in all treatments. Spores in extrametrical hyphae were absent and spore population per 100 gm soil was poor in all tree species. Formation of spores in root was maximum in Ber, followed by Aonla and Chironji. Among three tree species, maximum colonization index was recorded in Aonla followed by Ber and Chironji. Sporocarp formation maximum in Ber followed by Aonla and Chironji.

Data on colonization of Aonla, Ber and Chironji by *Glomus* 2 are presented in Table 4.26. Formation of arbuscules and vesicles was poor in all tree species. Good amount of extrametrical hyphae with spores were recorded in all treatments. Spores in root were absent in all tested tree species. Among three tree species, maximum colonization index was recorded in Ber, followed by Aonla and Chironji. Spore counts per 100 gm soil were absent in Aonla and Chironji, poor in Ber. Formation of sporocarp was maximum in Aonla, followed by Ber and Chironji.

Data on colonization of Aonla, Ber and Chironji by *Glomus* 3 are presented in Table 4.27. Formation of arbuscules was poor in Aonla and Chironji, absent in Ber. Vesicles formation was excellent in Ber and good in Aonla and Chironji. Presence of extrametrical hyphae was excellent in Aonla and Ber, good in Chironji. Spores in extrametrical hyphae were absent in all tested tree species. Spores in root were maximum in Aonla, followed by Ber and Chironji. Maximum colonization index was recorded in Ber, followed by Aonla and Chironji. Maximum spores counts per 100 gm soil was recorded in Aonla, followed by Chironji and absent in Ber. Sporocarp formation was good in Ber, poor in Aonla and absent in Chironji.

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Data on colonization of Aonla, Ber and Chironji by *Glomus* 4 are presented in Table 4.28. Formation of arbuscules was poor in Aonla, Ber and Chironji. Vesicles formation was excellent in Aonla and Ber, good in Chironji. Formation of extrametrical hyphae was maximum in Ber, followed by Aonla and Chironji. Formation of spores in extrametrical hyphae was absent in all tree species. Good amount of spore formation in root was recorded in Aonla and Ber, it was absent in Chironji. Maximum colonization index was recorded in Aonla, followed by Ber and Chironji. Spores counts per 100 gm soil were nil in all treatments. Sporocarp formation was poor in Ber and Chironji and it was absent in Aonla.

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Data on colonization of Aonla, Ber and Chironji by *Glomus* 5 are presented Table in 4.29. Formation of arbuscules was poor in all treatments. Vesicles formation was good in Aonla and Ber, poor in Chironji. Formation of extrametrical hyphae were recorded in all tested tree species. Spores in extrametrical hyphae were absent in all treatments. Formation of spores in root was poor in Aonla and absent in Ber and Chironji. Maximum colonization index was recorded in Aonla followed by Ber and Chironji. Spore counts per 100 gm soil were nil after sieving in all tested tree species. Sporocarp formation was poor in Aonla and Ber, absent in Chironji.

Data on colonization of Aonla, Ber and Chironji by *Glomus* 6 are presented in Table 4.30. Formation of arbuscules was poor in Aonla and Ber and absent in Chironji. Vesicles formation was good in Aonla and poor in Ber and Chironji. Formation of extrametrical hyphae was excellent in Ber, good in Aonla and poor in Chironji. Spores in extrametrical hyphae were absent in all treatments. Formation of spores in root was poor in Ber and absent in Aonla and Chironji. Maximum colonization index was recorded in Ber, followed by Aonla and Chironji. Spores were not obtained on test sieves in all tested tree species. Sporocarp formation was good in Ber and Aonla and it was absent in Chironji.

Table 4.24 Build up of VAM colonization in selected minor fruit trees after inoculation with *Acaulospora* 1

Character	Fruit tree		Observati	ons after	
		Two	Three	Four	Five
· ·		month	month	month	month
Arbuscules*	Aonla	+	-	+	-
	Ber	+	-	+	+
	Chironji	+	-	-	-
Vesicles*	Aonla	-	_	+	-
	Ber	-		-	-
	Chironji	+	-	-	- , '
Extrametrical	Aonla	++	+	+	++
hyphae*	Ber	++	+	+	+
	Chironji	-	+	+	+
Spores in	Aonla	-	-	_	-
extrametrical	Ber	-	- '	-	-
hyphae*	Chironji	-	-	- ,	-
Spores in root*	Aonla		· · ·	-	-
	Ber	<u>-</u>	-	-	-
	Chironji	-	-	-	-
Colonization	Aonla	1.1	0.0	2.3	0.0
index	Ber	4.5	0.0	1.5	0.8
	Chironji	8.9	0.0	1.5	0.5
Spore count per	Aonla	1191	1890	1320	488
100 g soil	Ber	3177	3315	2257	1081
	Chironji	0.0	14	11	20
Sporocarp*	Aonla	-		•	
	Ber	-			_
	Chironji		-	-	-
* - Absent	+ Present	++ Good	+++ Ex	cellent	

Table 4.25 Build up of VAM colonization in selected minor fruit trees after inoculation with *Glomus* 1

Characters	Fruit tree		Observati	ons after	
		Two	Three	Four	Five
		month	month	month	month
Arbuscules*	Aonla	-	-	_	+
	Ber	+	-	-	-
	Chironji	+	-	-	-
Vesicles*	Aonla	+++	+++	+++	+++
	Ber	+++	++	++	++
	Chironji	+++	-	_	+
Extrametrical	Aonla	+++	++	++	++
hyphae*	Ber	++	++	++	++
	Chironji	+++	++	++	++
Spores in	Aonla	-	· -	-	-
extrametrical	Ber	· -	-	-	_
hyphae*	Chironji	-	-	-	-
Spores in root*	Aonla	+	+	+	+
	Ber	+	++	++	++
	Chironji	- ·	+	+	++
Colonization	Aonla	53.1	35.6	35.6	26.3
index	Ber	42.2	15.9	15.9	15.3
	Chironji	42.5	1.2	1.3	7.5
Spore count per	Aonla	6.0	0	0	0.0
100 g soil	Ber	0.0	0	0	0.0
	Chironji	0.0	0	0	7.0
Sporocarp*	Aonla	+	- ·		+ ,
	Ber		+	++	+
	Chironji	-		_	+ 4,1
* - Absent -	+ Present	++ Good	+++ Exc	cellent	

Table 4.26 Build up of VAM colonization in selected minor fruit trees after inoculation with *Glomus* 2

Characters	Fruit tree		Observati	ons after	
		Two	Three	Four	Five
		month	month	month	month
Arbuscules*	Aonla	-	+	+	+
	Ber	+	_	-	++
	Chironji	+	-		+
Vesicles*	Aonla	· <u>-</u>	-	-	++
	Ber	-	-	-	+
	Chironji	++	-	-	+
Extrametrical	Aonla	++	++	++	++
hyphae*	Ber	++	++	++	++
	Chironji	+	++	++	++
Spores in	Aonla	++	+	+	+
extrametrical	Ber	++	+	+	+
hyphae*	Chironji	+	+	+	+
Spores in root*	Aonla	-	-	-	-
	Ber	-	-	-	- ·
	Chironji	<u> </u>	-	-	_
Colonization	Aonla	8.3	0.5	0.5	14.1
index	Ber	2.7	0.2	0.2	19.7
	Chironji	13.1	0.0	0.0	3.6
Spore count per	Aonla	0.0	0.0	0.0	0.0
100 g soil	Ber	3.0	0.0	0.0	0.0
en e	Chironji	0.0	0.0	0.0	0.0
Sporocarp*	Aonla	-	+	+	+
	Ber		+	+	+
	Chironji				+

Table 4.27 Build up of VAM colonization in selected minor fruit trees after inoculation with *Glomus* 3

Characters	Fruit tree		Observati	ons after	
		Two	Three	Four	Five
		month	month	month	month
Arbuscules*	Aonla	-	-	-	+
	Ber	~	-		-
	Chironji	-	-	-	+
Vesicles*	Aonla	++	+	+	++
	Ber	+++	++	++	+++
	Chironji	+	-	+ ,	++
Extrametrical	Aonla	++	++	++	++
hyphae*	Ber	+++	++	++	++
	Chironji	+	+	+	++
Spores in	Aonla	_		· -	_
extrametrical	Ber	- '		-	,
hyphae*	Chironji	-	-	-	-
Spores in root*	Aonla	+	++	1 ++ 1	++
•	Ber		+	+	+
	Chironji	+	+	+	-
Colonization	Aonla	17.7	8.0	8.0	21.4
index	Ber	34.8	18.6	17.9	33.4
	Chironji	9.9	0.0	5.8	22.8
Spore count per	Aonla	0.0	18	15	0.0
100 g soil	Ber	0.0	0.0	0.0	0.0
J	Chironji	30	10	4	0.0
Sporocarp*	Aonla		<u>-</u>	<u>.</u>	+
• •	Ber	+	++	+	+
	Chironji		<u> </u>	<u> </u>	<u> </u>
* - Absent	+ Present	++ Good	+++ Exc	ellent	

Table 4.28 Build up of VAM colonization in selected minor fruit trees after inoculation with *Glomus* 4

Characters	Fruit tree		Observati	ons after	
		Two	Three	Four	Five
		month	month	month	month
Arbuscules*	Aonla	-	+	+	_
	Ber	-	+ '	+	-
	Chironji	-	+	+	-
Vesicles*	Aonla	++	+	++	++
	Ber	++	+	++	+++
	Chironji	+	-	+	++
Extrametrical	Aonla	+++	++	++	++
hyphae*	Ber	++	+++	+++	1++
	Chironji	.+	+	+	++
Spores in	Aonla	-		-	, = 1
extrametrical	Ber	-	-	- ,	-
hyphae*	Chironji	-	-	-	-
Spores in root*	Aonla	+	+	+	1 + + + +
. -	Ber	-	+	+	+
	Chironji		-		-
Colonization	Aonla	20.8	5.8	20.2	15.8
index	Ber	28.1	1.4	5.6	26.3
	Chironji	5.5	0.0	1.5	10.5
Spore count per	Aonla	0.0	0.0	0.0	0.0
100 g soil	Ber	0.0	0.0	0.0	0.0
,	Chironji	0.0	0.0	0.0	0.0
Sporocarp*	Aonla			4. 1 - 11. 1	
	Ber	+			+
	Chironji	- 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1	<u>.</u>		+
* - Absent	+ Present	++ Good	+++ Exc	ellent	

* - Absent + Present ++ Good +++ Excellent

Table 4.29 Build up of VAM colonization in selected minor fruit trees after inoculation with *Glomus* 5

Characters	Fruit tree		Observati	ons after	
		Two	Three	Four	Five
		month	month	month	month
Arbuscules*	Aonla	-	+	+	_
	Ber	_	-	-	+
	Chironji	+	-	-	+ 1 1
Vesicles*	Aonla	- .	++	+	+++
	Ber	-	-	-	+++
	Chironji		-	-	+
Extrametrical	Aonla	+	++	++, *, .	++
hyphae*	Ber	++	++	++	++
	Chironji	+	+	+	+ +
Spores in	Aonla	-	_	_ ,	. -
extrametrical	Ber	· · · · · · · · · · · · · · · · · · ·	-	-	<u> </u>
hyphae*	Chironji	-	_	_	-
Spores in root*	Aonla	-	,	<u>-</u>	+
•	Ber	- -	•	-	-
	Chironji	-	~	-	-
Colonization	Aonla	0.0	13.0	13.0	55.6
index	Ber	2.5	0.2	0.2	56.4
	Chironji	13.9	0.0	0.0	4.5
Spore count per	Aonla	0.0	0.0	0.0	0.0
100 g soil	Ber	0.0	0.0	0.0	0.0
-	Chironji	0.0	0.0	0.0	0.0
Sporocarp*	Aonla		•		+
•	Ber			+	++
	Chironji	-			1 1 1 1 1 1
* - Absent	+ Present	++ Good	+++ Exc	ellent	

Table 4.30 Build up of VAM colonization in selected minor fruit trees after inoculation with *Glomus* 6

Characters	Fruit tree		Observati	ons after	
		Two	Three	Four	Five
		month	month	month	month
Arbuscules*	Aonla	-	+	_	_
	Ber	+	-	-	+
	Chironji	, -		-	-
Vesicles*	Aonla	-	+	+	++
	Ber	-	+	+	+
	Chironji	+	-	-	+
Extrametrical	Aonla	+	+	+	++
hyphae*	Ber	+++	+++	+++	+++
	Chironji	_	+	+	+
Spores in	Aonla		_	-	<u>.</u>
extrametrical	Ber	· · · · •	·	-	
hyphae*	Chironji	-	-	-	<u>.</u>
Spores in root*	Aonla	=	-	-	· ·
- -	Ber		+	+	+
	Chironji	· =	-	· -	
Colonization	Aonla	0.5	1.5	1.6	6.6
index	Ber	2.0	0.8	0.8	10.2
	Chironji	2.2	0.0	0.0	3.3
Spore count per	Aonla	0.0	0.0	0.0	0.0
100 g soil	Ber	0.0	0.0	0.0	0.0
	Chironji	0.0	0.0	0.0	0.0
Sporocarp*	Aonla		_i.^(,+-;	+ +	++
	Ber	+	++	++	++
	Chironji		+	+	+
* - Absent	+ Present	++ Good	+++ Exc	ellent	

4.6 Build up of VAM colonization in different crops in different seasons:

Build up of VAM colonization of different crops in different seasons (Rabi, Zaid and Kharif) was studied to identifying suitable conditions for maintenance of different VAM cultures.

4.6.1 Acaulospora 1: Data on build up of mycorrhizal colonization in roots of common crops of Bundelkhand after inoculation with Acaulospora 1 are presented in Table 4.31. Presence of arbuscules, vesicles and extrametrical hyphae was noticed in all tested crops. Formation of arbuscules was maximum in maize, formation of vesicles was maximum in black gram and green gram and good amount of extrametrical hyphae were recorded in gram, maize and pea. Spores in extrametrical hyphae and roots were absent in rhizosphere of all crops. Colonization index was maximum in maize. It was less then 20% in other crops. Excellent sporulation was noticed in maize, black gram and green gram during Kharif season. Formation of sporocarp was absent in rhizosphere of all tested crops. Maize, black gram and green gram were identified as good host for the fungus.

4.6.2 Glomus 1: Data on build up of mycorrhizal colonization in roots of common crops of Bundelkhand after inoculation with Glomus 1 are presented in Table 4.32. Presence of arbuscules, vesicles and extrametrical mycelium was recorded in all tested combinations. Formation of spores in extrametrical mycelium was absent but spores in roots were noticed in all crops. Maximum colonization index were recorded in maize during all seasons (Rabi, Zaid and Kharif) followed by black gram, green gram, pea, wheat and gram. Spores were not obtained after sieving. Sporocarp formation was recorded in rhizosphere in maize, green gram and black gram. It was absent in rhizosphere of gram, pea and wheat. In general, culture of this fungus could be maintained on maize with ease.

4.6.3 Glomus 2: Data on build up of mycorrhizal colonization in roots of common crops of Bundelkhand after inoculation with Glomus 2 are presented in Table 4.33. Formation of arbuscules was noticed in maize, wheat, pea and

gram. The fungus formed vesicles in the roots of all tested crops. Formation of extrametrical hyphae was seen in all tested combinations. The extrametrical hyphae were more in maize, green gram and black gram than gram, pea and wheat. Presence of spores in extrametrical hyphae was recorded in maize, green gram, black gram and gram. Formation of spores in root was not noticed. Spores were not obtained after sieving and spore counts were nil in all tested combinations. Among all tested crops, maximum colonization index was recorded in maize during all seasons. In other crops it was less then 10%. Presence of sporocarp was noticed in rhizosphere of maize, black gram and green gram. Maize was recognized as suitable host for the fungus.

4.6.4 Glomus 3: Data on build up of mycorrhizal colonization in roots of common crops of Bundelkhand after inoculation with Glomus 3 are presented in Table 4.34. Arbuscules formation was present in maize, green gram, black gram, pea, wheat and gram but in maize the rate of arbuscules formation was faster than others crops. Similarly by vesicles formation in maize was more than other crops. Formation of extrametrical hyphae were present in all tested combinations. The extrametrical hyphae was more in maize, black gram and green gram than gram, pea and wheat. Spores in extrametrical hyphae were not noticed in all tested combinations. Formation of spores in root was more in maize, black gram, green gram as compare to gram, pea and wheat. Spore count after sieving was nil in all tested crops. Among all tested crops, maximum colonization index was recorded in maize followed by green gram, black gram. In others crop colonization index was less than 20%. Presence of sporocarp was recorded in maize, black gram, green gram.

4.6.5 Glomus 4: Data on build up of mycorrhizal colonization in roots of common crops of Bundelkhand after inoculation with Glomus 4 are presented in Table 4.35. Abuscules were present in all tested crops, except gram. Formation of arbuscules was maximum in maize. Vesicles and extrametrical hyphae were noticed in all tested combinations. Vesicle formation was more in pea and maize than black gram, green gram, gram and wheat. Good amount of

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and the latter will be the relativity and the latter than the second of the second second

extrametrical hyphae were noticed in black gram, maize, green gram, pea, wheat and gram. Spores in extrametrical hyphae were absent in rhizosphere of all crops. Spores in root were present in all tested combinations, which were maximum in pea and maize. Colonization index was maximum in pea (15.58%), followed by maize (winter: 12.67%, summer: 19.67%, rain: 60.3%) black gram (summer: 8.33%, rain: 7.5%), green gram (summer: 8.36%, rain: 4.7%), wheat (3.47%) and gram (2.60%). Sporocarps were present in black gram, maize and green gram. Spore counts after sieving were absent in all tested combinations. Maize was recognized as good host.

4.6.6 Glomus 5: Data on build up of mycorrhizal colonization in roots of common crops of Bundelkhand after inoculation with Glomus 5 are presented in Table 4.36. Formation of arbuscules was present in maize, pea, wheat, gram and green gram. Arbuscules formation was absent in black gram. Presence of vesicles and extrametrical hyphae were noticed in all tested crops and spore formation in roots was recorded in maize, black gram and green gram. Colonization index was maximum in maize (winter: 21.56%, summer: 16.91%, rain: 57.7%), followed by pea (9.86%), black gram (summer: 7.35%, rain: 14.2%), green gram (summer: 10.60%, rain: 19.7%), wheat (4.51%) and gram (2.19%). Spore count after sieving was zero in all tested combinations. Sporocarp formation was recorded only in maize during month of OctoBer. Maize was identified as good host for the fungus.

4.6.7 Glomus 6: Data on build up of mycorrhizal colonization in roots of common crops of Bundelkhand after inoculation with Glomus 6 are presented in Table 4.37. Presence of arbuscules and vesicles was noticed in all tested crops, except gram. Presence of extrametrical hyphae was noticed in all tested crops, except wheat. Spores in extrametrical hyphae were noticed during Zaid and Kharif, but were absent during Rabi in all tested crops. Spores were present in root of all tested crops in small numbers except wheat. Maximum colonization index was recorded in maize (Rabi: 15.04%, Zaid: 10.08%, Kharif: 54.4%), while its value was less then 10% in other crops. Spores were

not obtained after sieving in all crops. Sporocarps were recorded during Zaid and Kharif but were absent during Rabi season in tested crops. Good amount of sporocarp formation was recorded in maize, black gram and green gram. Maize was recorded as suitable plant host for the fungus during Zaid and Kharif seasons.

Table 4.31 Build up of mycorrhizal colonization in roots of common crops of Bundelkhand after inoculation with *Acaulospora* 1

Character	Crops		(Observations	after	
		One	Two	Three	Four	Five
		month	month	month	month	month
Rabi (winter) crops						
Arbuscules*	Gram	+	-	-	- · · ·	
	Maize	-	++	+++	-	+++
	Pea	-	· -	+	+++	+
	Wheat	-	+	+	. · · . -	+
Vesicles*	Gram	-	+	++	- '	•
	Maize	-	+	<u>-</u>	++	++
	Pea	+	+	++	+	+
	Wheat	-	+	-	. · · · -	-
Extrametrical hyphae*	Gram	-	+	++	-	+ +
••	Maize	·	+	-	++	++
	Pea	· . +	+	++	+	-
	Wheat	_	+	-		- ,,
Spores in extrametrical	Gram			4	_	-
hyphae*	Maize	_	<u>.</u> .	n was en saint in die See See See See See See See See See Se	- 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1	
	Pea				-	_
	Wheat	_ · · .				
Spores in root*	Gram				i	_
opores in root	Maize	_	_	_		
	Pea	<u>-</u>	_			
	Wheat	<u></u>	_		_	
Colonization index	Gram	5.2	7.3	12.3	14.3	12.4
Colonization index	Maize	6.4	32.7	78.4	79.7	56.9
	Pea	2.8	14.8	15.3	18.2	9.1
	Wheat	2.8	14.8	14.1	6.3	6.4
C			0	20	4	14
Spore count per	Gram	0		0	0	1.5
100 g soil	Maize	0	0	18	25	1.5
	Pea	0	0		2.0	3
~ .	Wheat	0	0	21.2	2.0	,
Sporocarp*	Gram		- 1			-
	Maize	-	- -	1 4 - 1 4 13		
	Pea	-				
	Wheat	1. 1 . -				-
Zaid (summer) crops						
Arbuscules*	Maize	+++	+++	+	+++	+++
	Black gram	- 13 - 3	+			†
	Green gram	+	+ 1			+
Vesicles*	Maize		+	+	+	
	Black gram	+++	++	+	+	
	Green gram	+++	++	+ 1,1	+	.
Extrametrical hyphae*	Maize	+	+	4+	+	
	Black gram		+	+	+	
	Green gram	8 (+	++	++	
Spores in extrametrical	Maize				, Nastanija	
nyphae*	Black gram					
	Green gram					
Spores in root	Maize					
-r	Black gram					
	Green gram					

7 1 :-tion index	Maize	44.1	10	3.0	12.5	18.4
Colonization index	Black gram	30.5	17.8	4.9	5.3	2.2
	Green gram	34.4	23.3	7.1	6.4	1.4
a aunt nar	Maize	4	6	0	0	16
Spore count per	Black gram	1	3	0	0	0.0
100 g soil	Green gram	1	0	0	0	2.0
Sporocarp*	Maize	-	-	-	-	
Sporocarp	Black gram	-	~	<u> </u>		- ' -
	Green gram	-	-		-	-
Kharif (rainy) crops	1		++	+++		
Arbuscules*	Maize	+++		+		
•	Black gram		+	+		
	Green gram	+++	+	++		
Vesicles*	Maize	-	+++	+++		
	Black gram	+	+++	+		
	Green gram	-	++	++		
Extrametrical hyphae*	Maize	++	+++	+		
	Black gram	++	+	+		
	Green gram	++	++	T '		
Spores in extrametrical	Maize	-	-	· •		
hyphae*	Black gram	-	•			
J F	Green gram		-			
Spores in root*	Maize	+	++	+++		
Sports and	Black gram		+	+		
	Green gram	-	-	- -		
Colonization index	Maize	29.4	56.6	61.7		
Colomania	Black gram	15.3	54.9	53.3		
	Green gram	22.0	22.2	12.3		
Spore count per 100 g	Maize	0	0	0		
soil	Black gram	0	0	0		
	Green gram	0	0	0		
Sporocarp*	Maize	· · · · · ·	++	++		
· Sporoomp	Black gram	-	+			
	Green gram		+ Good	+++ Excellen		

Table 4.32 Build up of mycorrhizal colonization in roots of common crops of Bundelkhand after inoculation with *Glomus* 1

Page	Character	Crops		Ob	servations aft	er	
Rabi (winter) crops	On an	•	One	Two			
Arbuscules* Gram			month	month	month	month	month
Maize							
Maize	Arbuscules*	Gram	++	-	-	+ "	-
Vesicles* Gram + + + + + + + + + + + + + + + + + + +		Maize	++	+++	+++	+++	+++
Vesicles* Gram		Pea	++	+	-	-	++
Maize		Wheat	-	+	+	-	-
Maize	Vesicles*	Gram	+	++	++++	+++	++
Extrametrical hyphae* Gram Haize Head Haize Haize		Maize	+	+++	++	+++	+++
Extrametrical hyphae*		Pea	+	++	+++	+++	
Maize		Wheat	+	++	+	+	+ .
Maize	Extrametrical hyphae*	Gram	+	+	+ " , ,	+ 1	-
Pea	Excitation 115 P		++	++	++	+	+
Spores in extrametrical hyphae*			+	+	+	+	- 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1
Spores in extrametrical hyphae*			+	+	-	+	- 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1
Nyphae*	Spores in extrametrical		-	-	_	- * .	-
Pea			_	_		<u>-</u>	
Spores in root* Gram	пурпас			_	<u>-</u>	_	-
Spores in root* Gram			_	_	-	- .	-
Maize	Charas in root*		_	_	. _	++	+ +
Pea	Spores in root			_	·	++	+++
Colonization index			_		+	++	+
Colonization index							.
Maize 11.9 33.9 72.2 90.6 56.9	G 1		8.0	28.6	31.6	17.5	18.5
Pea 16.1 31.1 36.3 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 48.9 44.4 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 44.9 4	Colonization index						
Name	•						
Spore count per							
Naize Spore count per Stant							
Name Pea O O O O O O O O O							
Sporocarp* Wheat 0 0 0 0 0 0 0 0 0	100 g soil						
Sporocarp* Gram							
Maize - + + + + + + + + + + + + + + + + + +			0	U	<u> </u>	_	
Maize	Sporocarp*		- · · · · ·			+	+
Wheat - - - - - - - - -			-				
Zaid (summer) crops Arbuscules* Maize + ++++ +++++ +++++ ++++++ +++++++ ++++++++++++++ ++++++++++++++++++++++++++++++++++++			-		•		
Arbuscules* Maize		Wheat	- 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1	- ·			
Arbuscules* Maize					4.4	444	+++
Vesicles* Green gram	Arbuscules*		+,,				
Vesicles* Maize			-				
Vesicles* Maize + ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++ ++						44	++
Extrametrical hyphae* Maize - + + + + + + + + + + + + + + + + + +	Vesicles*						
Extrametrical hyphae* Maize -							+++
Extrametrical hyphae* Maize			++				
Black gram	Extrametrical hyphae*		<u> </u>				
Spores in extrametrical Maize - -							+
hyphae* Black gram Green gram - Spores in root* Black gram - H H H H H H H H H H H H			+		TT		
hyphae* Black gram Green gram Maize Black gram H H H H H H H H H H H H H	Spores in extrametrical						
Spores in root* Green gram Maize Black gram - + + + + + + + + + + + + + + + + + +		Black gram		그런 기가 살기			
Spores in root* Maize Black gram + ++++++++++++++++++++++++++++++++++							++
Black gram + ++ ++ ++	Spores in root*						
Continued		Green gram	<u> </u>		11	Con	

Colonization index	Maize	15.5	50.9	12.4	23.1	35.0
Colonization mack	Black gram	17.0	19.3	12.4	10.5	0.6
	Green gram	46.6	28.3	6.9	6.4	29.6
Spore count per	Maize	0	0	0	0.4	0
100 g soil	Black gram	0	0	0	0	0
100 8 3011	Green gram	0	0	0	Ö	ő
Sporocarp*	Maize	-	_	+	_	_
Sporocurp	Black gram		_	+	<u>-</u>	•
	Green gram	_		+	_	
Kharif (Rainy) crops	9					
Arbuscules*	Maize	+++	++	+++		
	Black gram	-	+	+		
	Green gram	+++	+ 1	+		
Vesicles*	Maize	-	+++	++		
V COICIOS	Black gram	+	+++	+++		
	Green gram		++	+ +		
Extrametrical hyphae*	Maize	++	· +++	++		
The state of the s	Black gram	++	+	+		
	Green gram	++	++	+		
Spores in extrametrical	Maize	_		_		
hyphae*	Black gram	_		<u>.</u>		
	Green gram	_	_	-		
Spores in root*	Maize	+	++	+++		
Spores and the	Black gram	_	+	+		
	Green gram					
Colonization index	Maize	29.4	56.6	61.7		
OOIOIII MAOI	Black gram	15.3	54.9	53.3		
	Green gram	22.0	22.2	12.3		
Spore count per	Maize	0	0	0		
100 g soil	Black gram	0	0	0		
2000	Green gram	0	0	0		
Sporocarp*	Maize	• • • • • • • • • • • • • • • • • • •	++	++		
oporoourp	Black gram	_	+			
	Green gram	_	+	en de la companya de La companya de la co		
* - Absent	+ Present		Good	+++ Excellent		

Table 4.33 Build up of mycorrhizal colonization in roots of common crops of Bundelkhand after inoculation with *Glomus* 2

Character	Crops			Observations	after	
		One month	Two month	Three month	Four month	Five month
Rabi (winter) crops						
Arbuscules*	Gram	+		+	-	- ,
	Maize	+++	+++	+++	+++	+++
	Pea	+	-	+	+	
	Wheat	+	+	+	-	-
Vesicles*	Gram	-	+	+	+ -	-
	Maize	+	+	++ -	+	1+11
	Pea		+	+	+ 1	
	Wheat	-	+	+	-	.
Extrametrical hyphae*	Gram	+ .	+	+	-	
	Maize	+	+++	++	++	+++
	Pea	- '	+	+ .	··· ·	
	Wheat	-		+	-	
Spores in extrametrical	Gram	-	-	+	-	
hyphae*	Maize	-	+ '	++	++	++
	Pea	-	-	<u>-</u>	e in ee e iste da	-
	Wheat	-	_	-		-
Spores in root*	Gram	-	-	-	<u>-</u>	
	Maize	· - ·	. • •	-	•	
	Pea	. •	r i e	• * • • • • • • • • • • • • • • • • • •		i - i - - i i i i
	Wheat	- . ·	-		-	
Colonization index	Gram	4.7	5.8	1.1	0	1.7
	Maize	41.9	48.9	65	51.3	46.6
	Pea	1.1	7.5	9.5	6.1	2.0
	Wheat	41.1	11.3	11.9	2.5	2.5
Spore count per	Gram	0	0	0	0	0
100 g soil	Maize	0	0	0	0	0
	Pea	0	0	0	0	0
	Wheat	0	0	0	0	0
Sporocarp*	Gram	- ·			ariet 📲 Literatu	
	Maize	•			+	++
	Pea	. · · · · · ·	4 / - 1	- 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1	et, j. a li Ali.	
	Wheat	-	<u>-</u>	-	<u>-</u>	
Zaid (summer) crops						
Arbuscules*	Maize	++	++		++	++
	Black gram			<u> </u>	-	++
	Green gram					+
Vesicles*	Maize	++	+	+		
	Black gram		+	, ** + , ** .		
	Green gram		-	+	+	•
Extrametrical hyphae*	Maize	+	+		+	+
	Black gram	+	++	+++	++	++
	Green gram	+ 1	+	+++	++	+
Spores in extrametrical	Maize		+			
hyphae*	Black gram		+	++		
	Green gram	+	+	++		+
Spores in root*	Maize		-			
						and the second s
	Black gram					

Colonization index	Maize	12.8	13.75	2.5	13.3	20.0
	Black gram	5.6	7.5	8.3	11.1	17.5
	Green gram	3.2	7.3	3.2	1.9	5.6
Spore count per	Maize	0	0	0	0	0
100 g soil	Black gram	0	0	0	0	0 4
	Green gram	0	0	0	.0	0
Sporocarp*	Maize	-		-	-	
ti√r Til	Black gram	-	-	++	-	, - 4.4.
	Green gram	_	-	+	-	
Kharif (rainy) crops						
Arbuscules*	Maize	++	+++	+++		
	Black gram	-	-	+		
	Green gram	+	-	+		
Vesicles*	Maize	+	+	++ :		
	Black gram	-	+	.=		
	Green gram	+	+	+		
Extrametrical hyphae*	Maize	+	+++	+++		
	Black gram	++	+	+		
	Green gram	++	+++	++		
Spores in extrametrical	Maize	<u>-</u>	++	++		
hyphae*	Black gram	+	. · · - · .	+		
	Green gram	+	++	to a sign of the s		
Spores in root*	Maize	-	•			
	Black gram	- ·	<u>-</u>			
	Green gram	· · · · · · · · · · · · · · · · · · ·	-	- 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1		
Colonization index	Maize	26.4	58.1	59.4		
	Black gram	0.0	2.5	3.3		
	Green gram	2.8	4.0	4.7		
Spore count per 100 g	Maize	0	0	0		
soil	Black gram	0	0	0 1 1		
	Green gram	0	0	0		
Sporocarp*	Maize	-	++	+++		
F	Black gram			++		
	Green gram	_	=	++		
* - Absent	+ Present	++ (Good	+++ Excellent		

Table 4.34 Build up of mycorrhizal colonization in roots of common crops of Bundelkhand after inoculation with *Glomus* 3

Character	Crops	Observations after					
		One	Two	Three	Four	Five month	
		month	month	month	month		
Rabi (winter) crops							
Arbuscules*	Gram	+	-	-	. +	+	
	Maize	+	-	+	+	+ +	
	Pea	-	+	+	+	· ·	
	Wheat	-	+	+	-	-	
Vesicles*	Gram	· _	- ,	· _ :	+	+ 1	
	Maize	_	+	+++	+++	+++	
	Pea	· <u>-</u>	-	-	+	+	
	Wheat	_	+	+	+	-	
Extrametrical hyphae*	Gram	_		_	++	+	
Extrametrical hypnae	Maize	+	+	+	++	+	
	Pea		_	+	++	 	
	Wheat	-	<u>-</u>	+			
G		-	_			1 + II+ 1 + 1 + 1 + 1 + 1 + 1 + 1 + 1 +	
Spores in extrametrical	Gram	-	-	- -			
hyphae*	Maize	<u>-</u>	-	• • • • • • • • • • • • • • • • • • •			
	Pea	- .	-	-	•		
	Wheat	,-	•	, *	-	-	
Spores in root*	Gram	-	-		++	+	
	Maize	- '	- :		++	++	
	Pea			·	++	+	
	Wheat	* * -	-	-	<u>-</u>	+	
Colonization index	Gram	1.7	0	0	5.6	3.6	
	Maize	14.7	16.6	52.7	46.7	55.5	
	Pea	0.0	0.78	0.93	6.5	5.3	
	Wheat	12.5	16.3	3.9	3.75	1.7	
Spore count per	Gram	4	0	0	3	0	
100 g soil	Maize	0	0	0	0	0	
100 5 3011	Pea	0	0	0	4	0	
	Wheat	Õ	Ö	0	0	0	
Sporocarp*	Gram	-	ž				
Sporocarp.	Maize				+	+	
	Pea	· •					
	Wheat		• • • • • • • • • • • • • • • • • • •	-	in Para		
Zaid (summer) crops					++	++	
Arbuscules*	Maize	++	++	+			
	Black gram	+		•			
	Green gram	+	+				
Vesicles*	Maize		+	+++	+++	+++	
	Black gram	+++	+	+	+		
	Green gram	+++	++	+	+	++	
Extrametrical hyphae*	Maize	+	+	++	# # # # # # # # # # # # # # # # # # #	++	
	Black gram	++	+	++	++	++	
	Green gram	++	+	+++	++	++	
Spores in extrametrical	Maize						
hyphae*	Black gram						
пурнас	Green gram						
Sparas in rac+*	Maize		+	+	+	++	
Spores in root*	Black gram		+	+++	+	+	
	DIACK GIAIII		+	+++	4.5	+	

Colonization index	Maize	23.9	27.8	8.6	21.3	32.5			
	Black gram	57.0	13.3	8.8	2.4	0.5			
	Green gram	62.2	16.1	12.4	1.25	17.2			
Spore count per	Maize	0	0	5	0	0			
100 g soil	Black gram	0	0	5	20	0			
	Green gram	0	0	0	25	0			
Sporocarp*	Maize	-	_	+	· -	-			
1	Black gram	-	+	+	- '.	-			
	Green gram	-	+	+	-	· -			
Kharif (rainy) crops	-								
Arbuscules*	Maize	++	++	++					
	Black gram	++	-	-					
	Green gram	++	+						
Vesicles*	Maize	+	+++	+++					
	Black gram	++	+++	+++					
	Green gram	<u>-</u>	+++	++					
Extrametrical hyphae*	Maize	+	+++	+++					
	Black gram	+	++	++					
	Green gram	+	++	++					
Spores in extrametrical	Maize	-	-	-					
hyphae*	Black gram		_	-					
	Green gram	· · · . <u>-</u>	-						
Spores in root*	Maize	-	++	· · · · · · · · · · · · · · · · · · ·					
. ~ F ***	Black gram		+	+					
	Green gram	<u> </u>	_	+					
Colonization index	Maize	26.4	38.3	45.2					
	Black gram	22.2	37.3	35.3					
	Green gram	12.1	35.8	22.8					
Spore count per	Maize	0	0	0					
100 g soil	Black gram	0	0	0					
, 100 B 5011	Green gram	0	0	0					
Sporocarp*	Maize	• • • • • • • • • • • • • • • • • • • •	·	++					
Sporocarp	Black gram			+					
	Green gram	_							
* - Absent	+ Present	++ G	ood	+++ Excellent					

Table 4.35 Build up of mycorrhizal colonization in roots of common crops of Bundelkhand after inoculation with *Glomus* 4

Character	Crops	Observations after					
		One	Two	Three	Four	Five	
		month	month	month	month	month	
Rabi (winter) crops							
Arbuscules*	Gram	-	-	-	-	-,	
	Maize	+	+	++	++	++	
	Pea	+	-		. -	-	
	Wheat	+	+	-	++	+ -	
Vesicles*	Gram		+	-	+	+	
	Maize	+	+	++	+	+	
	Pea	-	++	+++	++	+	
	Wheat	-	+	+	+	+	
Extrametrical hyphae*	Gram	+	_	-	-	-	
	Maize	-	+ +	+	+	++	
	Pea	-		+ 1	++	+	
	Wheat	+	-		+ 1	-	
Spores in extrametrical	Gram	-	<u>-</u>	-	-	-	
hyphae*	Maize	-	-	<u>-</u> ·		-	
	Pea	-	-	-		-	
	Wheat	-	-		-	-	
Spores in root*	Gram	- -	-	-	+ 1	+	
•	Maize	•	+	+ 1	-	+	
	Pea	-	-	+ ,	+++	t	
	Wheat	-	-	11 - 11 - 11	+		
Colonization index	Gram	0	4.2	0.5	4.2	4.1	
	Maize	0.9	13.8	24.4	8.0	16.25	
	Pea	2.8	15.8	29.4	15.8	14.1 *	
	Wheat	1.25	4.9	5.6	2.8	2.8	
Spore count per	Gram	0	0	0	0	0	
100 g soil	Maize	0	0	0	0	0	
	Pea	0	0	0	0	0	
	Wheat	0	0	0	0	0	
Sporocarp*	Gram	_		lag ul <mark>e</mark> ksi ili	_	<u>-</u> 111	
	Maize	_	aga 😉 👫			4 julije 1 m	
	Pea	- · · · · ·		-	+	-	
	Wheat	eri 🕳 jesti 🧸	<u> -</u>	-		-	
Zaid (summer) crops		+	_	+	+	++	
Arbuscules*	Maize	+	<u>-</u>		4	-	
	Black gram	-	+	<u>.</u>			
	Green gram		++	+	+++	++	
Vesicles*	Maize	+	++	+	• 1	+	
	Black gram	+	+	+		+	
	Green gram	<u>-</u>	+	+	++	+++	
Extrametrical hyphae*	Maize	+	+++	++	++	++	
Zamanion ioni ily pinao	Black gram	+	+	++	++	++	
	Green gram		<u> </u>			-	
Spores in extrametrical	Maize						
hyphae*	Black gram						
пуршас	Green gram				+	++	
Spores in root*	Maize)	+		
Spores mirot	Black gram		+		+		
	Green gram	7.4	13.6	9.68	29.38 Cont	38.3	

... Continued

Colonization index	Maize	7.5	17.4	4.84	6.41	5.5
	Black gram	10.5	7.8	0.31	0.48	22.7
	Green gram	0	0	0	0	0
Spore count per	Maize	0	0	0	0	ŏ
100 g soil	Black gram	0	0	0	0	0
	Green gram	-	-	-	_	· · · · · ·
Sporocarp*	Maize	_	+	+	_	<u>.</u>
	Black gram	-	_	-	_	-
	Green gram					
Kharif (rainy) crops						
Arbuscules*	Maize	++	+++ , .	+++		
	Black gram		-	+		
	Green gram	+	-	+		
Vesicles*	Maize	+ .	+ 1 1 1	++		
	Black gram	-	, +			
	Green gram	+	+ + -	+		
Extrametrical hyphae*	Maize	+	+++	+++		
	Black gram	++	+	+		
	Green gram	++	+++	++		
Spores in extrametrical	Maize	· -	++	.++		
hyphae*	Black gram	+ -		+		
	Green gram	+	++,	+		
Spores in root*	Maize	-	-	-		
in the state of th	Black gram	-	_	-		
	Green gram	- , ·		-		
Colonization index	Maize	26.4	58.1	59.4		
	Black gram	0.0	2.5	3.3		
	Green gram	2.8	4.0	4.7		
Spore count per 100 g soil	Maize	0	0	0		
	Black gram	0	0	0		
	Green gram	0	0	0		
Sporocarp*	Maize		++	+++		
The state of the s	Black gram	• • • · · ·	- -	++		
	Green gram	_		++		

Table 4.36 Build up of mycorrhizal colonization in roots of common crops of Bundelkhand after inoculation with *Glomus* 5

Character	Crops			bservations		
		One month	Two month	Three month	Four month	Five month
Rabi (winter) crops		IIIOIIIII		IIIOIIII		- IIIOIIII
Arbuscules*	Gram	_	+		-	
Albuseules	Maize	+	+	++	+++	+++
	Pea	+	+	+	+	-
	Wheat	_	_	+	· ·	
Vesicles*	Gram	_	_	+	+	
Vesicies	Maize	_	+	+		+ + *
	Pea	_	_	++	++	+
	Wheat	_	<u>.</u>	+	+	+
Extrametrical hyphae*	Gram	_	- -	_	<u>.</u>	
Extrametrical hypitae	Maize			+	_	_
	Pea	~	_	_	+	2.50
	Wheat	-	+	+	+ **	
Spores in extrametrical	Gram	_	_			
hyphae*	Maize		- 10 - 10 - 10 - 10 - 10 - 10 - 10 - 10			_
пурнае	Pea	_	<u>-</u>	_	**************************************	<u>.</u>
	Wheat	_	-	_	_	•
Spores in root*	Gram		_	_	tan kale <u>i</u> i kantu	_
Spores in root	Maize	_				_
	Pea		-	_	ing a second of the second of	
	Wheat	_		_		-
Colonization index	Gram	1.6	0.63	3.4	2.8	2.5
Colonization index	Maize	2.1	10.0	19.2	35.9	40.6
	Pea	1.6	1.7	21.1	22.5	2.4
	Wheat	0.63	2.0	3.9	10.8	5.20
Spore count per	Gram	0.03	0	0	0	0
100 g soil	Maize	0	Ö	0	0	0
100 g son	Pea	0	0	Ŏ	0	0
	Wheat	0	Ö	Ŏ	0	0
Sparagern	Gram	-				
Sporocarp	Maize					
	Pea					
	Wheat		_	•		_
Zoid (summer) erons	Wilcat					
Zaid (summer) crops Arbuscules*	Maize	+++	+++			+
Albuscules	Black gram			_		
	Green gram	+	+			-
Vesicles*	Maize	+	+++	+	+	+
A 0210102	Black gram	+		+	+	+
	Green gram	++	++	+	++	
Extrametrical hyphae*	Maize		++	++	++	+++
Extramentear hypnac	Black gram	+	+++	+	++	++
	Green gram	+		+	++	+
Spores in extrametrical	Maize					
hyphae*	Black gram					
пурнас	Green gram					•
Spores in root*	Maize				44.1 B. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1.	
Photes in 1001	Black gram		+	+		
	Green gram		+ 3	+		
	Groom Brann				Contin	rued

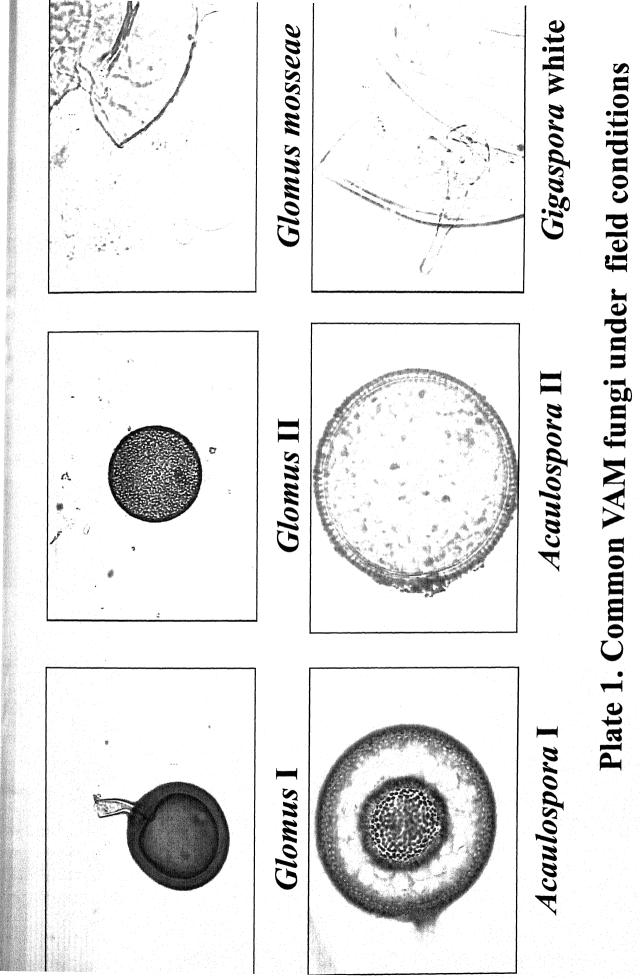
Colonization index	Maize	16.1	39.2	3.75	3.59	21.9
	Black gram	13.6	4.5	8.0	10.63	0.0
	Green gram	26.4	15	2.34	8.28	1.0
Spore count per	Maize	0	0	0	0	0
100 g soil	Black gram	0	0	0	0	0
	Green gram	0	0	0	0	0
Sporocarp*	Maize	-	-	-	•	• . •
	Black gram	-	-	_	-	· -
	Green gram	-	- ,	-	-	· •
Kharif (rainy) crops						
Arbuscules*	Maize	++	++	+		
	Black gram	-	-	-		
	Green gram	-	+	-		
Vesicles*	Maize	+++	+++	+++		
	Black gram	- ,	++	++ (
	Green gram	-	+++	++		
Extrametrical hyphae*	Maize	+	+	+++		
	Black gram	++	+	+		
	Green gram	+ 2	+	+		
Spores in extrametrical	Maize	-		-		
hyphae*	Black gram	· -	-	· · · · · •		
	Green gram			- '		
Spores in root*	Maize		-	+++		
	Black gram	-	-			
	Green gram			, - .		
Colonization index	Maize	31.4	40.8	57.7		
	Black gram	0.0	18.3	14.2		
	Green gram	4.8	29.2	19.7		
Spore count per	Maize	0	0	0		
100 g soil	Black gram	0	0,0	0		
성숙 취임하다	Green gram	0	0	0		
Sporocarp*	Maize	taga Ta <u>e</u> isa	-			
	Black gram	. -				
	Green gram		<u>-</u>	<u> </u>		
* - Absent	+ Present	++ (Good	+++ Excellent		

Table 4.37 Build up of mycorrhizal colonization in roots of common crops of Bundelkhand after inoculation with *Glomus* 6

Character	Crops		Ob	servations a	fter	
		One month	Two month	Three month	Four month	Five month
Rabi (winter) crops						
Arbuscules*	Gram	-	<u>-</u>	-	-	-
	Maize	+	+	. ++	+++	+
	Pea	+	-	-	•	-
	Wheat	+	+	-	-	. - 1
Vesicles*	Gram	- .	•	_	• •	• · · · ·
	Maize	+	+	+	+	+
	Pea	-	-	-	·	+ **
	Wheat	-	-	-	-	+
Extrametrical hyphae*	Gram	_	-		-	+
	Maize	- '		+	+	+
	Pea	_		-	• • • • • • • • • • • • • • • • • • •	+
	Wheat	* -	. - *,	, -		-
Spores in extrametrical	Gram	-	-	-	-	-
hyphae*	Maize	- <u>-</u>	-	. · ·	. - 1	<u>-</u>
	Pea	, v - ,	-	<u>-</u>		-
	Wheat	_	<u>.</u>	_	-	
Spores in root*	Gram			_	+	<u>-</u>
	Maize		_	+	+	+
	Pea	, -	-	+	+	`
	Wheat	-			<u>-</u>	-
Colonization index	Gram	0.16	0.0	0.47	0.47	0.15
	Maize	3.0	17.8	23.3	23.3	7.8
	Pea	0.5	0.5	0.3	0.3	1.25
	Wheat	3.0	2.0	0.78	0.78	4.4
Spore count per	Gram	0	0	0	0	0
100 g soil	Maize	0	0	0	0	0
100 5 501	Pea	0	0	0	0	0
	Wheat	0	0	0	0	0
Sporocarp*	Gram	_		_		- 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1
Sporocurp	Maize	<u>-</u>				<u>-</u>
	Pea	_	•			-
	Wheat			-	-	- ·
Zaid (summer) crops	77 11000					
Arbuscules*	Maize	++	++	+	++	++
Airouseures	Black gram	+				
	Green gram		1			
Vesicles*	Maize	기관에 일하네요	14 (+
Vesicies	Black gram	+	+	+	+	+
	Green gram	+	+	_		<u>-</u>
Extrametrical hyphae*	Maize		+	+	++	++
Extramedical hypnac	Black gram	+	++	++	+++	++
	Green gram		, 11 1 1 1 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	++		++
Spores in extrametrical	Maize		하는 보호로 된다.			
hyphae*	Black gram					
пурнас	Green gram					
Spares in root*	Maize		등 이 그림을 하다 다			<u>.</u>
Spores in root*	Black gram					
			+	+		
	Green gram				Contir	med

... Continued

Colonization index	Maize	26.9	26.7	3.1	12.8	20.9
	Black gram	6.9	8.1	0.63	1.71	5.6
	Green gram	4.5	4.3	0.0	0.31	1.3
Spore count per	Maize	0	0	0	0	0
100 g soil	Black gram	0	0	0	0	0
	Green gram	0	0	0	0	0
Sporocarp*	Maize	-	- ,	-	+	+
	Black gram	-	+	++	++	+ * * * * * * * * * * * * * * * * * * *
	Green gram	-	-	+	+	· - ·
Kharif (rainy) crops						
Arbuscules*	Maize	+++	+++	+++		
	Black gram	-	. -	+		
	Green gram	-	-	+		
Vesicles*	Maize	. -	+	+		
	Black gram	+	+	+		
	Green gram	<u>-</u> ,	+	+		
Extrametrical hyphae*	Maize	++	+++	+++		
	Black gram	++	+++	++		
	Green gram	++	* +	+++		
Spores in extrametrical	Maize		. - •	+		
hyphae*	Black gram	_	-	+		
	Green gram	-		+		
Spores in root*	Maize		-	+		
	Black gram	•	+	+		
	Green gram	-	· •			
Colonization index	Maize	30.2	26.2	54.4		
	Black gram	1.4	26.1	5.9		
	Green gram	0.9	10.2	5.5		
Spore count per	Maize	0	0	0		
100 g soil	Black gram	0	0	0		
	Green gram	0	0	0		
Sporocarp*	Maize	<u> </u>	++	++		
	Black gram		++			
	Green gram		+	+		
* - Absent	+ Present	++	Good	+++ Excellent		



Spore colour: Brown

Spore size:

Mean: 115 x 115 µ Range: 108 – 127 µ

Composite wall width: 13.0 µ

No. of wall groups: 2

Muranym: A (U_o)B(UM)

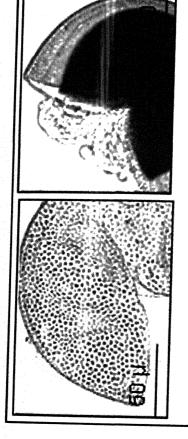
Hyphal terminus: Present

Wall reaction to Meltzer's reagent: Present

Spores formation within mots: Absent

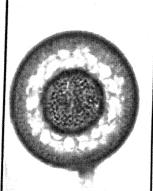
Sporocarp: Absent

Surface ornamentation: Present

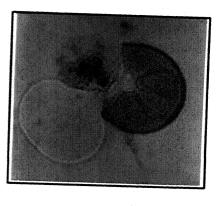


Spore





Endospore



Hyphal terminus

Plate 2. Characteristics of Acaulospora 1

Spore colour: Dark yellow

Spore size:

Range - 84 - 120 x 86 - 125 µ Mean - 96 x 96 µ

Composite wall width: 7.2 µ

No. of wall groups: 1

Muranym: ? A (L)

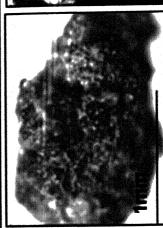
Attachment: Present

Wall reaction to Meltzer's reagent: Absent

Spores formation within roots: Present

Sporocarp: Present

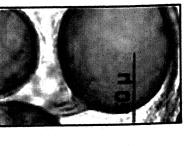
Colour of sporocarp: Blackish yellow



Spores in root

Spores in sporocary

Sporocarp



Spore

Plate 3. Characteristics of Glomus 1

Spore colour: Light yellow

Spore size:

Mean: 49 x 49 µ

Range: 36 - 72 µ

Composite wall width: 3.5 µ

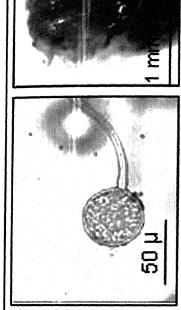
No. of wall groups: 1

Spores formation within roots: Absent

Spore with extra metricular hyphae: Present

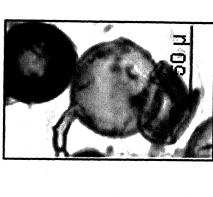
Sporocarp: Present

Colour of sporocarp: Light brownish yellow



Spore

Sporocarp



Reaction to Meltzer's reagent

Spore

Plate 4. Characteristics of Glomus 2

Spore colour: Yellow to light brown

Spore size:

Mean: 84 x 81 µ Range: 60 - 124 x 55 - 120 µ

Composite wall width: 4.2 µ

Number of wall groups: 1

Muranym: ? A (L)

Spores formation within roots: Present

Sporocarp: Present

Colour of sporocarp: Yellow to brown

Sporocarp

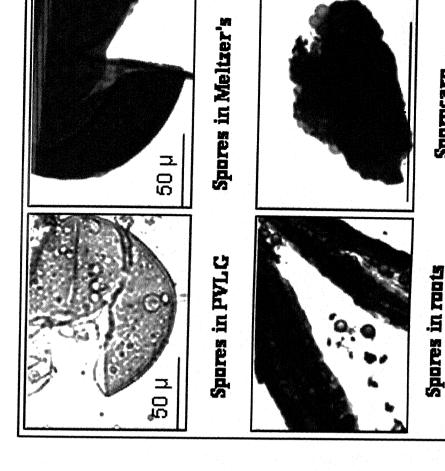


Plate 5. Characteristics of Glomus 3

Spore colour: Brownish yellow

Spore size:

Mean: 76 x 76 µ

Range: 38 – 115 x 43 – 103µ

Composite wall width: 5.0 µ

No. of wall groups: 1

Muranym: ? A (L)

Spores formation within roots: Present

Sporocarp: Present

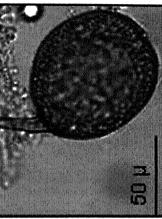
Colour of sporocarp: Yellow (Turmeric)





Sporocarp

Sporocarp with spores



20 p

Spore in PVLG

Spore in Meltzer's reagent

Plate 6. Characteristics of Glomus 4

Spore colour: Creamish yellow

Spore size:

Mean: 59 x 56 µ

Range: 36 - 96 x 33 - 76 µ

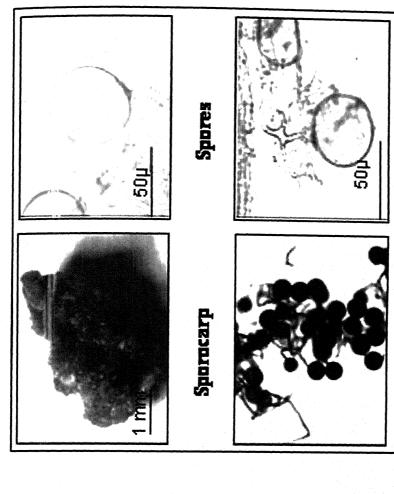
Composite wall width: 2.5 - 5.0 µ

No. of wall groups: 1

Spores formation within roots: Present

Sporocarp: Present

Colour of sporocarp: Creamish yellow



Reaction to Meltzer's Spore in root

reagent

Plate 7. Characteristics of Glomus 5

Spore colour: Silver shiny

Spore size:

Mean: 54.2 x 54 µ

Kange: 48 - 72 x 48 - 67 µ

Composite wall width: 2.4 µ

No. of wall groups: 1

Spores formation within roots: Present

Sporocarp: Present

Colour of sporocarp: Creamish yellow

reagent

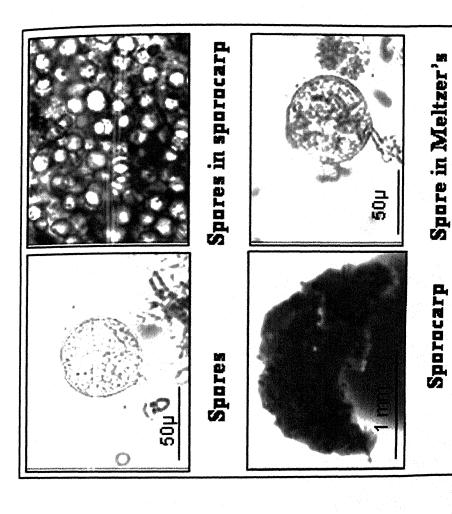


Plate 8. Characteristics of Glomus 6

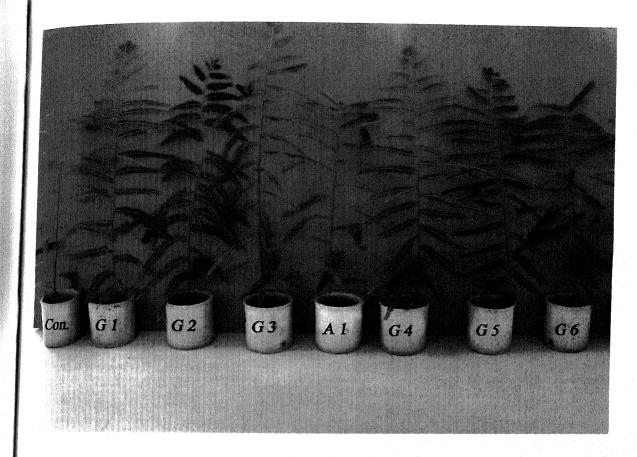


Plate 9. Effect of inoculation of VAM species on growth of Aonla (Emblica officinalis Gaertn.) seedlings

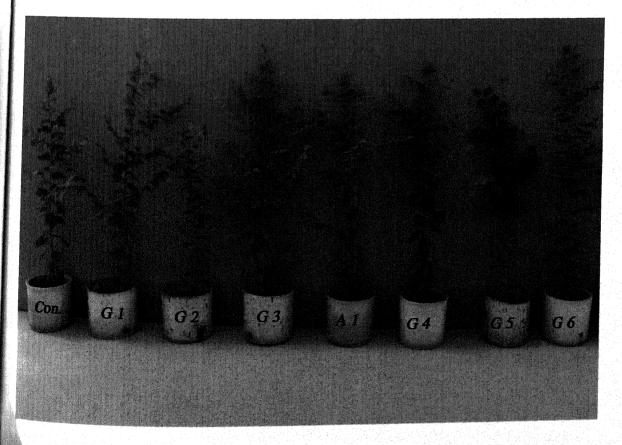


Plate 10. Effect of inoculation of VAM species on growth of Ber (Zizyphus mauritiana Lamk.) seedlings

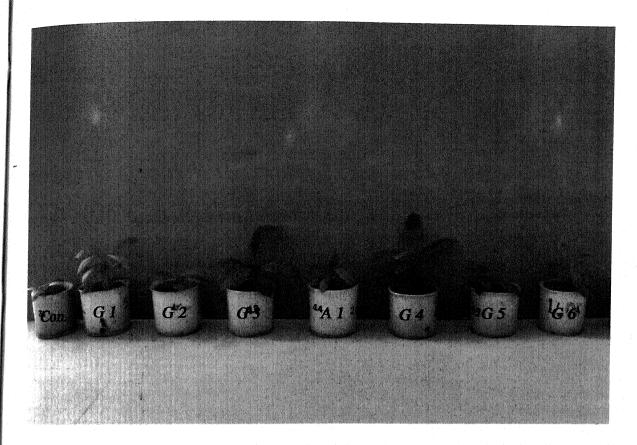


Plate 11. Effect of inoculation of VAM species on growth of Chironji (Buchanania lanzan Spr.) seedlings

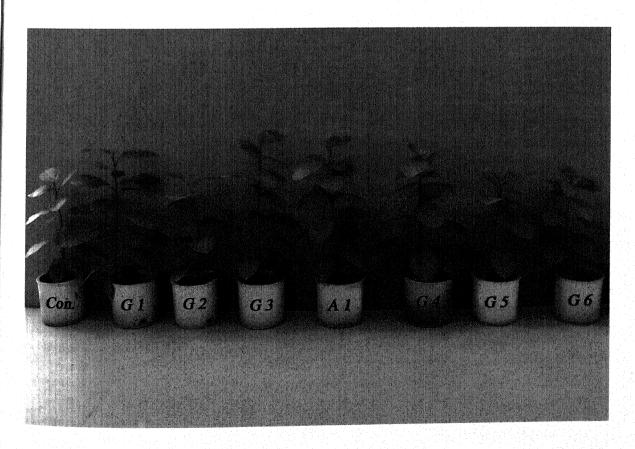


Plate 12. Effect of inoculation of VAM species on growth of Lasoda (Cordia myxa Roxb.) seedlings

Discussions

DISCUSSIONS

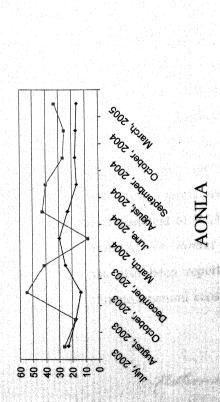
The results obtained from all the experiments conducted in the present study are discussed hereunder in detail with an attempt to through light in field surveys, identification of common VAM fungi in rhizosphere of Aonla, Ber, Chironji and Lasoda, culturing, purification and multiplication of VAM fungi and screening of the fungi for improved seedling growth under nursery conditions.

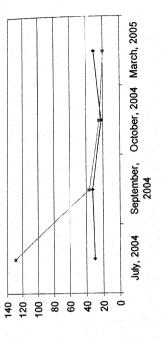
5.1 Colonization of Aonla, Ber, Chironji and Lasoda Roots By Vesicular Arbuscular Mycorrhizal Fungi: Observations on VAM activity in Aonla were recorded in its four varieties viz., Chakaiya, Kanchan, Krishna and NA-7, on nine sampling dates (Table 4.1). Maximum colonization index was noticed in variety Krishna (22.7%), followed by Kanchan (20.0%), Chakaiya (16.5%) and NA-7 (16.3%). Observations in Krishna were at par with Kanchan and superior to Chakaiya and NA-7. VAM spore count per 100 g soil in rhizosphere of different Aonla varieties were at par, which ranged from 9.2 to 12.9. The data on colonization index in rhizosphere of Ber varieties recorded during different seasons are presented in Table 4.8 and 4.9. Values for colonization index of different Ber varieties (Banarasi Karaka, Gola and Seo), its Desi plants and three wild relatives (Ghot, Jharberi and Makor) did not differ significantly. Whereas, spore count (number per 100 g soil) was maximum in Banarasi Karaka (29.5), followed by Ghot (28.8), Gola (25.8), Jharberi (22.4) and Makor (21.0). Poorest spore counts were recorded in Desi (19.2) and Seo (15.3).

Contrasting reports on susceptibility of varieties of a given plant species to VAM fungi are available in literature. For example, Sieverding (1991) has reported little differences between cassava clones in their susceptibility to VAM fungi in terms of colonization index. Whereas, Devagiri et al. (2001) reported seed source dependent variation in mycorrhizal

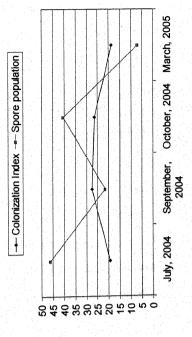
colonization in *Dalbergia sissoo*. Twenty nine seed sources from India and Nepal were screened to identify good mycorrhizas forming seed sources. Results indicated good amount of variation among different seed sources with respect to VAM colonization index (24 to 54%). Krishna *et al.* (1985) found in their investigation on the horizontal susceptibility of finger millet to VAM fungi that genetic factors responsible for high levels of infection were "dominant" when cultivars of high and low susceptibility were crossed. Optimum infection ratings (not necessarily the highest ratings) are prerequisites for the physiological effectiveness of the symbiosis.

Results on colonization index and spore count in rhizosphere of Chironji and Lasoda are presented in Table 4.10 and 4.12. Differences in colonization index values of both trees were non-significant during different sampling dates. In Chironji, the values were at par at Jakhlon and Nilkanth and in Lasoda, it was maximum in silvi-pasture plot NRCAF (32.9%), followed by block plantation NRCAF (22.4%) and Nareta (16.9%). In both trees, the counts were maximum during July 2004, followed by September 2004, June 2005 and March 2005. In Chironji, spore counts per 100 g soil were at par at two sampling sites. In Lasoda, it was maximum in block plantation NRCAF (20.3) followed by silvi-pasture NRCAF (15.4) and Nareta (2.0). The soils were red textured at all sampling sites except Nareta, where its texture was black. Thus, the VAM activity was more in red soil than black soil in Lasoda and development of the fungi was more during rains as compared to other seasons in both trees. Plots of colonization index and spore population v/s date of samplings in tested tree species exhibited a set pattern. Formation of fresh roots was observed at faster rate when sufficient soil moisture was available in the field, especially during rainy season. Colonization of these newly formed roots took some time. But during this period, increased VAM activity was recorded in terms of increased spore population. After rainy season, rate of fresh root formation declined, soil moisture reduced and major portion of live





BER



LASODA

March, 2005

September, 2004

July, 2004

25 26 5 5 5

39

CHIRONJI

Fig. 5.1 Colonization index and spore population of VAM fungi in Aonla, Ber, Chironji and Lasoda during different months of the year

fine roots became mycorrhizal. But in absence of fresh roots, VAM activity as a whole, declined along with spore population (Fig. 5.1).

In present study, good level of mycorrhization reported for above mentioned tree species by VAM fungi is consistent with information available in literature. VAM fungi have the widest host range and distribution of all the mycorrhizal associations. It is estimated that about 90% of vascular plants normally establish mutualistic relationship with VAM fungi. VAM fungi have been observed in 1000 genera of plants representing some 200 families. According to Gerdemann (1975), it is easier to list most plant families that do not form VAM mycorrhizae than to list those that do. Families not forming VAM mycorrhizae include Pinaceae, Betulaceae, Orchidaceae, Fumariaceae, Commelinaceae, Urticaceae, and Ericaceae. Families that rarely form VAM mycorrhizae include the Brassicaceae, Chenopodiaceae, Polygonaceae, and Cyperaceae.

5.2 Common VAM Species: Three species of Glomus, two species of Acaulospora, three species of Gigaspora and two species of Scutellospora were recorded in rhizosphere of Aonla, Ber, Chironji and Lasoda (Fig. 5.2). Glomus was most predominant genus, followed by Acaulospora and Gigaspora. Photographs of some common local VAM species are shown in Plate 1. Glomus I was most abundant species in rhizosphere of all tested four tree species, followed by Glomus II (except in Ber) where Acaulospora I had second rank. Acaulospora II and a light green coloured Gigaspora species (especially in Aonla) were also quite common. Presence of Glomus mossae and some other species was meager. The reported results are in agreement with few reports available in literature on dominance, distribution and establishment of VAM fungi in natural ecosystems. Bhatia et al. (1996) have reported that Glomus is well adapted to fertile soil with high nutrient levels. It has also been reported from all types of soils in tropical and temperate climates, natural ecosystems and disturbed lands (Mukerji, 1996), through the

species represented within the genus may vary. Genera of Scutellospora, Acaulospora and Gigaspora are more abundant in soils having low nutrient levels (Koske, 1987). So presence of spores of Acaulospora, Gigaspora and Scutellospora in rhizosphere of Aonla, Ber, Chironji and Lasoda in good numbers reflects the poor nutritional status of local soils.

5.3 Colonization Index, Spore Count and Species Composition in Aonla Rhizosphere Variety NA-7 With and Without Wheat As An Intercrop:

Data on colonization index and spore count per 100 g soil in Aonla rhizosphere variety NA-7 with and without wheat as an intercrop are presented in Table 4.6. During crop period, colonization index was significantly superior in Aonla plants with wheat (28.4%) than in Aonla plants grown without wheat (20.2%). While during pre- crop and post- crop periods, it was at par in both treatments i.e. with (22.5%, 23.7%) and without wheat (25.6%, 24.3%). The observed differences can be explained on the basis of better moisture availability in agroforestry plot, as the intercrop was irrigated. The observations on VAM spore count per 100 g soil from rhizosphere of Aonla plants grown with wheat were at par with respective observations on Aonla plants grown without wheat, during all above mentioned crop periods. VAM species composition did not show any qualitative changes in these observations, however quantitative changes were recorded. Thus, the results showed that wheat as an inter-crop increased VAM activity in Aonla rhizosphere during crop period. Kumar et al. (2007) have reported that VAM colonization index of eucalyptus roots was significantly more in agroforestry plots (29.7%) than in pure plantation (13.7%). Further, it has been reported that in Siris (Albizia procera (Roxb.) Benth.) based agroforestry systems intercropping increased the inoculum potential of VAM fungi in tree rhizosphere.

Fallow has been reported by many workers to reduce soil population of VAM fungi (Barbara and Hetrick, 1984). Therefore, more extensive green

Table 5.1 VAM species composition in rhizosphere of selection minor fruit crops

VAM species		Number*	of spores	in	Total
	Aonla	Ber	Chironji	Lasoda	
Glomus I	617	946	43	60	1666
Glomus II	245	146	17	35	443
Glomus mosseae	0	0	1	0	1
Acaulospora I	127	246	2	16	391
Acaulospora II	91	78	0	1	170
Gigaspora sp.	56	32	0	0	88
Scutellospora I	0	0	1	0	1
Scutellospora II	0	0	0	1	1
Total	1136	1448	64	113	2761

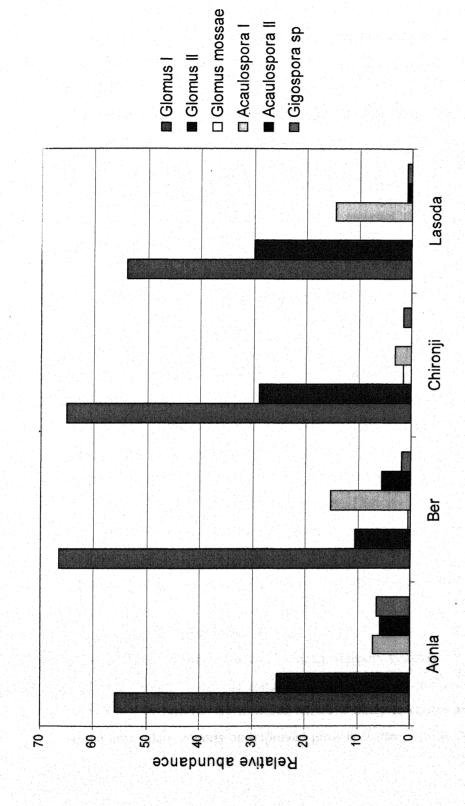


Fig. 5.2 Relative abundance of VAIM species in rhizosphere of some selected minor fruit trees

cover and biological diversity in agroforestry systems as compared to pure block plantation may enrich the VAM-mycorrhizal flora of soil. Though, VAM fungi are obligate symbionts but these are non specific in their selection of host (Bonfante and Fasolo, 1987). These have been reported to have at least 300,000 receptive hosts, representing 200 families. Some individual VAM fungi may have access to thousand of hosts (Kendrick and Berch, 1985). Thus, possibility of cross infectivity among tree and crop components of a given agroforestry systems exist, which is likely to improve soil VAM-mycorrhizal microflora. Reid and Bowen (1979) have reported that maximum VAM colonization of Medicago plants occurred at field capacity and it reduced under conditions which were either too wet or too dry. Thus, the improved moisture conditions of agroforestry systems with irrigated inter-crops like wheat may increase the population of VAM fungi in soil compared to dry soils of pure plantation. Sieverding (1991) has reported that small phosphate applications generally may improve VAM fungal activities on infertile soils and their population benefits from N application probably due to longer maintenance of photosynthetic leaf area. In selected experimental fields in present study, the fertilizers were applied to intercrops not to tree. So tree component must be receiving these at sub optimal level, which might have improved the VAM flora under tree canopy. Thus the observed increase in VAM population due to intercropping can be due to following possible reasons:

- 1. Presence of more extensive green cover in agroforestry systems
- 2. Better moisture and nutrient availability
- 3. Improved soil conditions
- 4. Cross infection of trees and crops in agroforestry systems by VAM fungi

In conclusion, it can be stated that inter-cropping increases activity of VAM fungi in agroforestry systems, which is likely to confer many benefits on the host. Many reports on improved growth of trees, which may be partly

due to VAM fungi, in agroforestry systems than in pure plantations are available (Chaturvedi and Pandey, 2000; Mathur and Sharma, 1983).

5.4 VAM Activity in Rhizosphere of Upland and Low Land Aonla Plants:

Data on colonization index and spore count of VAM fungi in rhizosphere of Aonla (variety Krishna) under water-logged (lowland) and normal conditions (upland), recorded from July 2003 to October 2004 are presented in Table 4.4. Mean colonization index was significantly superior in upland plants (22.7%) as compared to water logged plants (13.6%). Similar trend was recorded for VAM spore count per 100 g soil in upland (11.6) and lowland plants (7.3). The index and spore count were significantly more in upland plants than lowland plants during July 2003 and August 2003. Normal rains were received during this period (Appendix I). In October 2003 rains stopped, the index value in lowland plants increased during this month and was at par with respective value in upland plants, but spore count remained significantly more in upland plants. The weather remained more or less dry from October 2003 to May 2004. Index value in upland (more porous red soil) recorded sharper increase than in lowland plants (black soil) up to March 2004 and the spore count declined in both treatments during this dry period. With the start of rains during June 2004 both index and spore count showed sharper increase in upland plants as compared to lowland plants. But the monsoon declined early in August 2004. The index remained significantly superior in upland plants during August 2004 and September 2004, but the spore count declined in both treatments. As indicated earlier, formation of fresh roots in the trees was observed at faster rate when sufficient soil moisture was available in the field, specially during rainy season. Colonization of these newly formed roots took some time. But during this period, increased VAM activity was recorded in terms of increased spore population. After rainy season, rate of fresh root formation declined, soil moisture reduced and major portion of live roots became mycorrhizal. But in absence of fresh roots, VAM activity as a whole,

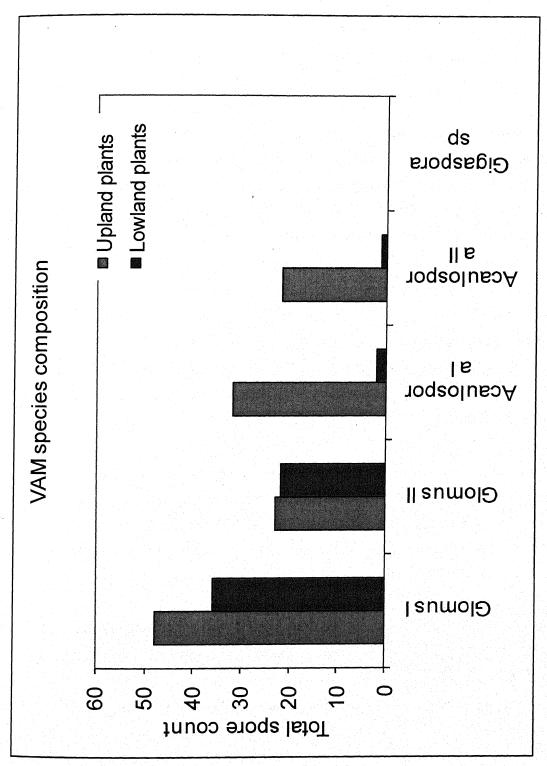


Fig. 5.3 VAM Species composition in rhizosphere of upland and lowland of Aonla variety krishna

declined along with spore population. In upland plants four VAM species were recorded viz. *Glomus* I, *Glomus* II, *Acaulospora* I and *Acaulospora* II. In lowland plants, only *Glomus* species were observed. Similar trends in mycorrhization of upland and lowland plants were recorded in Aonla (Kumar and Bisaria, 1999) and Hardwickia plantations (Kumar and Bisaria, 2000) during rainy season in 1997 and 1999, respectively.

Thus, the results clearly showed that VAM activity in terms of colonization index, spore count and mycorrhizal diversity were more in rhizosphere of upland plants than lowland plants and Glomus species had better adaptability to water logged conditions. This increase could be due to submerging of roots during rainy season and heavy soil texture in low lying part of the field. Reid and Bowen (1979) have reported that VAM activity is reduced under conditions which are either too wet or too dry. They found that maximum VAM colonization occurred at -0.2 bar water potential. VAM colonization dropped with each further decrease in water potential. VAM colonization was reduced to 50% of the maximum when the soil was saturated. Redhead (1975) has also reported similar results in that VAM spore production was excellent when Khaya plants were watered daily in sand cultures. Weekly watering reduced spore germination by 90% and watering twice per day (water logging) reduced spore production by 75%. Under water saturation condition, O2 diffusion is limited and anaerobiosis may develop which can result in the release of toxic compounds such as Mn, H₂S, and various organic acids. Reduced 02 concentrations can severely inhibit VAM spore germination and root colonization (Mosse et al. 1981; Saif 1981).

5.5 Effect of Soil Type on VAM Activity: Results on effect of different soil types on colonization index of Aonla, soil moisture, soil surface temperature and soil temperature at 10 cm depth during summer months are shown in Table 4.14. Maximum colonization was recorded in lateritic soil (27.9%), which was significantly more than colonization in red (21.2%) and black soils

(17.9%). The index significantly increased from March 2005 (21.9%) to April 2005 (27.4%), significantly reduced from April 2005 to May 2005 (19.3%) and the observations during May 2005 and June 2005 (22.0%) were at par. In black soil, observations on colonization index during different months remained at par. In lateritic soil, the index values, significantly increased from March 2005 to April 2005 then significantly decreased from April 2005 to May 2005 and were at par during May 2005 and June 2005. The trend in red soil was similar to lateritic soil except that the value was significantly more during June 2005 than May 2005 value. Maximum soil moisture was recorded during June 2005 (6.4%), followed by April 2005 (4.7%) and May 2005 (3.6%). High values of soil moisture during June 2005 were due to rains just before sampling date. Among different soil types, maximum percent soil moisture was recorded in black soil (5.7%), followed by lateritic soil (4.8%) and red soil (4.2%). Maximum soil temperature at 10 cm depth was recorded during May 2005 (46.3°C), followed by June 2005 (44.3°C) and April 2005 (36.4°C). Differences in sub-soil temperatures were non-significant in different soil types. Maximum soil surface temperature was recorded during May 2005 (71.4°C), followed by June 2005 (59.4°C) and April 2005 (46.4°C). Among three soil types, maximum surface temperature was recorded in black soil (61.7°C), followed by lateritic soil (59.0°C) and red soil (56.5°C). Thus, the results showed that maximum VAM activity was present in lateritic soil, followed by red soil and black soil. Results also showed that maximum percent soil moisture and soil surface temperatures were recorded in black soil, followed by lateritic soil and red soil. Soil surface temperature did not effect the sub soil temperatures in the root zone and the temperature at 10 cm depth was not significantly different in studied soil types. Though, VAM development in the roots is directly related to soil moisture below saturation point (Reid and Bowen, 1979), yet the slightly higher amount of soil moisture available in black soil was found insufficient to raise the VAM activity to levels, recorded in other soil types. Better VAM fungi activity recorded in

lateritic soil than other soil types can be due to better aeration. Reduced O₂ concentration has been reported to inhibit VAM spore germination and root colonization (Mosse *et al.*, 1981; Saif, 1981).

5.6 <u>Effect of Different VAM Inoculations on Growth of Selected Minor</u> Fruit Trees:

5.6.1 Aonla: Results on effect of inoculation of different VAM species on growth and P uptake of Aonla (Emblica officinalis Gaertn.) seedlings are presented in Table 4.20 and Fig. 4.7. Shoot length was significantly increased by Glomus 1 and Glomus 4. Collar diameter was significantly increased by Glomus 1. Glomus 1, Glomus 6, Glomus 4 and Glomus 3 significantly increased fresh shoot weight, Glomus 1, Glomus 4, Acaulospora 1, Glomus 3 and Glomus 6 significantly increased dry shoot weight and Glomus 1, Glomus 6, Acaulospora 1, and Glomus 3 significantly increased dry root weight. Maximum phosphorus uptake per plant was recorded in Glomus 3 (97.197 mg), followed by Acaulospora 1 (72.383 mg) and Glomus 6 (57.977 mg), which were significantly superior to control. Glomus 1 was ranked as most efficient VAM fungi for Aonla, based on observations made on P uptake per plant, shoot dry weight and root dry weight, followed by Acaulospora 1 and Glomus 3 (Table 5.2).

5.6.2 Ber: Results on effect of inoculation of different VAM species on growth and P uptake of Ber (Zizyphus mauritiana Lamk.) seedlings are presented in Table 4.21 and Fig. 4.8. None of tested AM fungi increased shoot length and collar diameter of Ber. Glomus 1 (48.07 g) and Glomus 6 (38.78 g) significantly increased shoot fresh weight. Glomus 3 (62.42 g), Glomus 4 (59.43 g) and Glomus 6 (57.90 g) significantly increased root fresh weight. Glomus 1 significantly increased dry shoot weight and Glomus 3, Glomus 6, Glomus 4 (22.37 g) and Glomus 1 significantly increased dry root weight. Maximum phosphorus uptake per plant was recorded in Glomus 3 (75.897 mg) followed by Glomus 1 (68.507 mg) and Glomus 6 (64.537 mg), which were significantly superior to control. Glomus 3, Glomus 6 and Glomus 1 were

found superior to other VAM fungi in enhancing seedling dry biomass and P uptake by Ber seedlings (Table 5.2).

5.6.3 Chironji: Results on effect of inoculation of different VAM species on growth and P uptake of Chironji (Buchanania lanzan Spr.) seedlings are presented in Table 4.22 and Fig. 4.9. At harvest, shoot length of Chironji seedlings was significantly more in Glomus 4 (23.2 cm), Glomus 6 (19.8 cm), Glomus 1 (18.5 cm), Glomus 3 (16.7 cm) and Glomus 5 (13.5 cm) than control (10.3 cm). Significantly superior collar diameter was recorded in Glomus 4 (7.5 mm), Glomus 6 (7.0 mm), Glomus 1 (6.4 mm), Acaulospora 1 (5.5 mm), Glomus 5 (5.3 mm) and Glomus 3 (5.2 mm) as compared to control (3.9 mm). Glomus 6 (21.0 g), Glomus 4 (20.6 g), Glomus 1 (14.7 g) and Glomus 3 (10.0 g) significantly increased fresh shoot weight and Glomus 4 (23.8 g), Glomus 6 (21.0 g), Glomus 1 (17.8 g) and Glomus 3 (14.9 g) significantly increased fresh root weight. Glomus 4 (7.7 g) Glomus 6 (7.1 g), Glomus 1 (5.0 g) and Glomus 3 (4.0 g) significantly increased dry shoot weight. Glomus 4 (8.6 g), Glomus 6 (7.1 g), Glomus 3 (4.8 g) and Glomus 1 (4.6 g) significantly increased fresh shoot weight. Maximum phosphorus uptake per plant was recorded in Glomus 6 (22.487 mg) followed by Glomus 1 (15.733 mg), Acaulospora 1 (15.570 mg) and Glomus 4 (12.857 mg), which were significantly superior to control. Glomus 6 was ranked as most efficient VAM fungi for Chironji, based on observations made on P uptake per plant, shoot dry weight and root dry weight, followed by Glomus 4 and Glomus 1 (Table 5.2).

5.6.4 Lasoda: Results on effect of inoculation of different VAM species on growth and P uptake of Lasoda (*Cordia myxa* Roxb.) seedlings are presented in Table 4.23 and Fig. 4.10. Shoot length was significantly increased by *Glomus* 4 (60.2 cm) and *Glomus* 5 (57.8 cm). None of tested VAM fungi increased collar diameter of Lasoda. *Glomus* 4 (64.4 g), *Glomus* 5 (62.8 g) and *Glomus* 1 (58.6 g) significantly increased fresh shoot weight and *Glomus* 2 (106.1 g) and *Glomus* 4 (100.1 g) significantly increased fresh root weight.

Table 5.2 Rank analysis of VAM fungi for their efficiency based on dry biomass and P uptake by selected minor fruit trees.

Plant growth			Rank	of cultures			
parameters	Acaulospora	Glomus	Glomus	Glomus	Glomus	Glomus	Glomus
	. 1	1	2	3	4	5	6
<u>Aonla</u>							
P uptake per plant	2	5	7	1	4	6	3
Shoot dry weight	3	1	7	4	2	6	5
Root dry weight	3	1	7	4	5	6	2
Total	8	7	21	9	11	18	10
Rank	II	I	VII	III	$\mathbf{v} = \mathbf{v}$	VI	IV
<u>Ber</u>							
P uptake per plant	4	2	7	1	5	6	3
Shoot dry weight	6	1	7	3	4	5	2
Root dry weight	6	4	7	1	3	5	2
Total	16	7	21	5	12	16	7
Rank	IV	II	\mathbf{V}	I	III	IV	II
Chironji							
P uptake per plant	3	2	6	5	4	7	1
Shoot dry weight	5	3	7	4	1	6	2
Root dry weight	5	4	6	3	1	7	2
Total	13	9	19	12	6	20	5
Rank	V	III	VI	IV	II	VII	. I
<u>Lasoda</u>							
P uptake per plant	6	1	2	3	5	4	7
Shoot dry weight	7	3	5	6	1	2	4
Root dry weight	7	4	1	2	3	5	6
Total	20	8	8	11	9	11	17
Rank	\mathbf{v}	I	, I	III	II	III	ΙV

None of tested VAM fungi increased dry shoot weight and *Glomus* 2 (106.1 g) and *Glomus* 4 (100.1 g) significantly increased fresh root weight. *Glomus* 1 (110.767 mg), *Glomus* 2 (86.423 mg), *Glomus* 3 (84.143 mg), *Glomus* 5 (82.943 mg), *Glomus* 4 (80.703 mg), *Acaulospora* 1 (80.557 mg) and *Glomus* 6 (78.737) significantly increased P uptake. *Glomus* 1 was ranked as most efficient VAM fungi for Lasoda, based on observations made on P uptake per plant, shoot dry weight and root dry weight, followed by *Glomus* 2 and *Glomus* 4 (Table 5.2).

Species and strains of VAM fungi have been shown to differ in the extent to which they increase nutrient uptake and plant growth (Abbott *et al.*, 1978; Carling *et al.*, 1980; Daniels *et al.*, 1981; Mosse, 1972; Nemec *et al.*, 1978; Powell, *et al.*, 1980 and Sanders *et al.*, 1977). These observations have led to a discussion of efficient or superior strains of mycorrhizal fungi (Powell *et al.*, 1976). Such terminology has often been used with the implication that any given species may have some kind of "innate effectiveness". There are at least four factors which are related to effectiveness of VAM fungi:

- 1. The ability to form extensive and well distributed hyphae in soil
- 2. The ability to form extensive infections throughout the developing root system
- 3. The ability of hyphae to absorb phosphorus from the soil solution
- 4. The longevity of the transport mechanism along hyphae and into the root (Abbott et al., 1982).

These characteristics are all involved with the uptake and transport of nutrients and they may differ for different species or strains of fungi. The only one of these four characteristics which has so far been shown to differ among species of VAM fungi is the ability to infect roots. There have been no reports which compare VAM fungi for their ability to form hyphae in soil, absorb phosphorus from the soil solution, or transport phosphorus along hyphae and into the root. The fungi may indeed differ in any of these three attributes.

However, currently we only have data to show that they differ in their ability to infect roots rapidly and/ or extensively.

Where the development of infection has been studied with time in relation to plant growth, those species which were effective at increasing plant growth were the ones which resulted in the most rapid and extensive infection of roots (Sanders *et al.*, 1977). The rate at which different fungal species reach their plateau infection level will depend upon the number of infective propagules and their ability to spread within soil or along and within roots by secondary infections (Daniels *et al.*, 1981; Powell *et al.*, 1981 and Smith *et al.*, 1981). The effectiveness of a particular species of VAM fungus will also be related to its ability to infect roots of the host at a time most appropriate for increased uptake of a nutrient which is deficient for plant growth.

Frequently, at a final harvest, there is no difference in the percentage of roots infected by different species of fungi although they may have produced differences in plant growth (Owusu *et al.*, 1979). This could arise if fungi differed in the rate at which they formed mycorrhizae (Abbot *et al.*, 1978).

Species of VAM fungi may indeed differ in their ability to from hyphae in soil, (Bevege et al., 1975), both in the distribution and quantity of hyphae. It has already been shown that the development of infection is correlated with the ability of a fungus to increased plant growth (Abbott et al., 1981). However, we do not know whether the growth of external hyphae is a characteristics which is independent of the development of infection with in roots. Do species of VAM fungi have a constant and "innate" ability to take up nutrient and increased plant growth which is independent of the ability of the fungus to infect the host? So far there is no evidence to suggest this. More research is needed to define the characteristics which make fungi efficient at enhancing plant growth. Clearly, there is scope for selecting fungi for field inoculation which are more efficient at increasing plant growth than those already residents in many soils. To be successful however, they must also have characteristics which enable them to persist after inoculation (Abbott and

Table 5.3 List of efficient vesicular arbuscular mycorrhizal (VAM) fungi for different agricultural plant species

Plant Species	Efficient mycorrhizal fungus/fungi	Mycorrhizal fungi tested	Parameters evaluated	References
<u>Agriculture crops</u> Allium cepa (Onion)	Gigaspora margarita	G. margarita, G. calospora, and a known AM fungus	Leaf number, dry matter, P-uptake, bulb yield	Ramana and Babu (1999)
Amorphophallus paeonufolius	G. calospora Glomus mosseae + G. aggregatum	G. margarita, G. calospora, and a known AM fungus G. mosseae, G. aggregatum, Gigaspora albida, Pisolithus tinctorius	Root colonization Tuber yield / plant	Ramana and Babu (1999) Ganesan and Mahadevan (1994)
Ananas comosus	Glomus fasciculatum	G. fasciculatum, Glomus sp., Acaulospora sp., Scutellospora sp	Plant growth, nutrition	Jaizme-Vega and Azcon (1995)
Acacia milotica	Glomous mosseae + Gigaspora gilmorei	G. mosseae, G. constrictum, Gigaspora gilmorei, and their combinations	Collar diameter, root -shoot dry weight and length	Mandal and Kaushik (1994)
Acacia auriculaeformis	Glomus etunicatum, G. macrocarpum	G. etunicatum, G. macrocarpum, G. fasciculatum, G. mosseae	Height, diameter, biomass, P-uptake	Aggangan, Lorilla, and Cruz
Acer saccharum (Sugar maple)	Glomus macrocarpum	G. macrocarpum, G. clarum, G. epigaeum, G. mosseae	Leaf number, mean lateral root number	(1990) Reid, Parker, Mitchell et al.
Azadirachta indica (neem)	Glomus mosseae	Glomus mosseae, G. fasciculatum, and seven other VAM fungi	Plant height, stem girth, biomass, P-content, zinc concentration, root colonizations	(1988) Sumana and Bagyaraj (1999)

Cajanus cajan	Glomus clarum	G. fasciculatum and seven other VAM fungi	Plant growth	Diederichs (1992)
	Glomus etunicatum	G. etunicatum, Gigaspora margarita	Shoot dry matter, nutrient uptake	Ahiabor and
Capsicum	Glomus intraradices	G. intraradices, indigenous mixed culture, commercial inoculum (Mycorise & C)	Fruit yield	Gaur, Adholeya, and Mukerji (1998)
Carica papaya	Glomus fasciculatum	G. fasciculatum, Glomus sp., Acaulospora sp., Scutellospora sp.	Plant growth, nutrition	Jaizme-vega and Azcon (1995)
Cacocasia esculenta	Glomus mosseae+ G. aggregatum	G. mosseae, G. aggregatum, Gigaspora albida, Pisolithus tinctorius	Tuber yield / plant	Ganesan and Mahadevan (1994)
Cucumis sativus	Glomus caledonium	G. caledonium, Glomus sp.	P-uptake	Joner and
Eleusine coracana	Glomus caledonicum	G. caledonicum, G. mosseae, G. fasciculatum, G. epigaeum (G. versiforme), Gigaspora calospora, G. margarita	Mycorrhizal efficacy, root colonization	Jokobsen (1994) Tewari, Johri, and Tandon (1993)
Fragaria xananassa (micropropagated)	Glomus versiforme 36- 366	G. versiforme (2 isolates), G. mosseae, G. etunicatum	Yield, production of runners	Taube-Baab and Baltruschat (1996)
Glycine max	Acaulsopora scrobiculata	A. scrobiculata, Glomus intraradices, and four other AM fungi	Plant growth, crop yield	Vasuvat, Nopamornbodi, and Thamsurakul
Lycopersicum esculentum	Glomus etunicatum	Glomus etunicatum, G. mosseae	Shoot dry weight, plant height	(1987) McGraw and Schenck (1981)

cv. Manapal	G. mosseae	Glomus etunicatum, G. mosseae	Root colonization	McGraw and
cv. Walter	G. mosseae	Glomus etunicatum, G. mosseae	Shoot weight, plant height	Schenck (1981) McGraw and
Manihot esculenta (cassava)	G. fasciculatum	G. fasciculatum, G. mosseae, G. constrictum, Glomus etunicatum Acaulsopora morrowea	Root colonization, plant weight, shoot and root dry weight	Schenck (1981) Sivaprasad, Sulochana and Nair (1990)
Manihot esculenta (cassava)	G. mosseae + G.aggregatum	G. mosseae, G.aggregatum, Gigaspora albida, Pisolithus	Tuber yield/ plant	Ganesan and Mahadevan
Medicago sativa	Glomus intraradices	G. intraradices, G. mosseae, Gigaspora margarita	Root colonization, fungal sporulation	Douds, Galvez, Becard et al.
Musa acuminata	Glomus fasciculatum	G. fasciculatum, Glomus sp., Acaulospora sp., Scutellospora sp.	Plant growth, nutrition	Jaisme-Vega and Azeon (1995)
Oryza sativa cv. Prakash	Glomus intraradices	G. intraradices, G. fasciculatum	Grain yield	Secilia and
Orzya sativa (upland	Acaulospora spinosa	Acaulospora spinosa, A. scrobiculata	Plant biomass, grain yield, root	Bagyaraj (1994) Ammani and Rao (1996)
Persea Americana	Glomus fasciculatum	G. fasciculatum, Glomus sp., Acaulospora sp., Scutellospora sp.	Plant growth, nutrition	Jaizme-vega and Azcon (1995)
Polianthes tuberosa (rajnigandha)	Glomus intraradices	G. intraradices, indigenous mixed cultures, commercial inoculum	Fruit yield, spike length	Gaur, Adholeya, and mukerji
Trifolium (Clover)	Acaulospora trappei	(information). A. trappei, A. laevis, Acaulospora sp.,	Root colonization	Gazey, Abbott, and Robson

(1992)

Triticum aestivum wheat	Glomus intraradices	G. intraradices, Gigaspora margarita	Plant yield, number of grains/spike	Asif Khan, Khan
(var. Swift)				et al (1995)
Vigna mungo (black	Glomus epigaeum (G.	G. epigaeum, Acaulospora spinosa, A.	Root colonization, shoot dry weight,	Rao and Rao
gram)	versiforme)	тоггожае	N and P. concentrations	(1996)
Vigna radiata (green	Glomus epigaeum (G.	G. epigaeum, Acaulospora spinosa, A.	Root colonization, shoot dry weight,	Rao and Rao
gram)	versiforme)	тоггожае	N and P concentrations	(1996)
Vigna unguiculata	G. etunicatum	G. etunicatum, Gigaspora margarita	Shoot dry matter, nutrient uptake	Ahiabor and
			,	Hirata (1994)
Vigna unguiculata	G. etunicatum	Glomus etunicatum, G. claroideum,	Top dry weight	Obura, Skipper,
cv. Kalumanu K&U		Glomus sp.		and Wagner
Vigna unguiculata cv.	G. claroideum	Glomus etunicatum, G. claroideum,	Top dry weight	Obura, Skipper,
California No. 5 black		Glomus sp.		and Wanger
Zea mays (pioneer 3905)	Glomus etunicatum	G. etunicatum, G. mosseae, G.	Leaf mass, protein concentrations	Boucher, Dalpe
		aggregatum, G. verstjorme		and Charest
Nephrolepis exaltata	Glomus intraradices, G.	G. intraradices, G. clarum, G.	Root infection	Ponton, Piche,
var. whitmanii (fern) micropropagated plants	clarum	versicultjerum, G. versiforme		Parent et al.
Tree Cross				(0661)
Malus domestica	Glomus mosseae	G. mosseae, G. macrocarpum	Root colonization, plant height, plant	Miller, Bodmer,
(apple)			growth	and Schuepp (1989)
Hevea brasiliensis	Glomus clarum, Glomus	G. clarum, Glomus sp., A. spinosa,	Dry weight	İkram, Mahmud,
	<i>Sp.</i>	Gigaspora margarita, Entrophospora colombiana, Glomus sp., and three		and Othman (1993)
		other species		
Tectona grandis	Glomus leptotichus	Not mentioned	Seedling growth parameters	Rajan, Reddy,
				and Bagyaraj (2000)

Zizvphus mauritiana	Glomus fasciculatum	G. fasciculatum, G. mosseae,	Growth, root colonization, nutrient	Mathur and Vyas
		Scutellospora calospora	uptake	(1996)
Citrus jambhiri (rough	Glomus fasciculatum	G. fasciculatum, G. mosseae, G.	Plant height, top weight, root weight,	Nemec (1979)
lemon)		etunicatum	chlamydospores in soil	
Persea American	Glomus fasciculatum	Glomus fasciculatum, Acaulospora	Plantlet growth and nutrition	Jaizme-vega and
(avocado)		sp., Scutellospora sp.		Azcon (1995)

Robson, 1982). A detailed list of efficient VAM fungi reported to be associated with different agricultural other plant species is given in Table 5.3.

5.7 <u>Build up of Colonization by VAM Fungi of Different Crops in</u> <u>Different Seasons</u>: Results on build up of colonization by VAM fungi of different crops in different seasons (rabi, zaid and kharif) showed that maize was the best host for isolated *Acaulospora* and *Glomus* species among tested crops(Table 4.31 - 4.37).

Choosing the host plant on which to produce VAM inoculation is often difficult. The plants should be well adapted to the conditions under which it must be grown, be an acceptable host for the VAM species which will be produced (Daft et al., 1974 and Reeves et al., 1979), grow rapidly and produce an abundance of roots, and have no pathogens in common with the host for which the VAM inoculum is ultimately intended. Since most plants are mycorrhizal with VAM fungi, a wide variety of plants are available for use in inoculum production. Some hosts which have been used include Nardus stricta, Coprosoma robusta, Citrus, Sorghum, Stylosanthes, Coleus, onion, pepper, strawberry, barley, corn, peanut, cotton and asparagus. Bagyaraj and Manjunath (1980) screened eight grasses for suitability for mass production of VAM inoculum and Guinea grass (Panicum maximum Jacq.) was found to be superior to other species tested, including Sorghum. Ferguson (1981) examined a variety of host plants for their suitability in producing VAM inoculum. This work indicated that both peanut and alfalfa were superior to Sorghum in producing VAM spores.

Summary

The first description is the first of

SUMMARY

The present study was carried out to identify suitable VAM species for inoculation of Aonla, Ber, Chironji and Lasoda. To achieve this, experiments on field surveys, identification of common VAM fungi in rhizosphere of above mentioned tree species, culturing, purification and multiplication of VAM fungi and screening of the fungi for improved seedling growth were conducted. The results obtained from various experiments are summarized below:

Among tested varieties of Aonla, maximum colonization index was recorded in Krishna (22.7%), followed by Kanchan (20.0%), Chakaiya (16.5%) and NA-7 (16.3%). Observations in Krishna were at par with Kanchan and superior to Chakaiya and NA-7. Spore counts per 100 gm soil in rhizosphere of different varieties were at par, which ranged from 10.8 to 12.9. Five VAM species belonging to three genera namely, *Glomus, Acaulospora* and *Gigaspora*, were common in rhizosphere of different Aonla varieties. Maximum total spore count was recorded for *Glomus 1* (234), followed by *Glomus II* (107), *Acaulospora 1* (105), and *Acaulospora II* (52). The poorest spore count was recorded for *Gigaspora* (11). The better counts were recorded during rainy seasons than during drier periods.

Colonization index was significantly superior in upland plants (22.7%) as compared to water logged plants (13.6%). Total spore counts were also more in upland plants (125) than lowland plant (61). The results indicated that *Glomus* species had better adaptability to water logged conditions in Aonla plants than other VAM species.

Results on effect of intercropping on mycorrhization of Aonla showed that colonization index was significantly superior in Aonla plants with wheat (38.4%) than in Aonla plants grown without wheat (24.6%) during crop period. While during pre- crop and post- crop periods, it was at par in both treatments i.e. with (18.7%, 23.7%) and without wheat (20.9%, 24.3%),

respectively. The observed differences can be explained on the basis of better moisture availability in agroforestry plot, as the intercrop was irrigated. The observations on VAM spore count per 100 g soil from rhizosphere of Aonla plants grown with wheat were at par with respective observations on Aonla plants grown without wheat, during all above mentioned crop periods. VAM species composition did not show any qualitative changes, however some quantitative changes in species composition were recorded.

Among different Ber varieties/wild relative maximum colonization index was recorded in Banarsi karaka (32.1%) and Seo (32.1%), followed by Ghot (30.0%), Makor (28.6%), Jharberi (28.1%) and Desi (27.8%). The poorest index value was recorded in Gola (24.3%). However, the difference in the colonization index of different Ber variety/wild relative were non-significant. Maximum VAM spore count was recorded in Banarsi Karaka (29.5 per 100 g soil), followed by Ghot (28.8 per 100 g soil), Gola (25.8 per 100 g soil), Jharberi (22.4 per 100 g soil) and makor (21.0 per 100 g soil). The poorest spore count was recorded in Desi (19.2 per 100 g soil) and Seo (15.3 per 100 g soil). Maximum total spore count was recorded for *Glomus I* (496), followed by *Acaulospora 1* (191), *Glomus II* (75), *Acaulospora II* (49) and *Gigaspora* (11). The poorest spore count was recorded for *Glomus mossae* (3).

Differences in colonization index values of Chironji at its two sites i.e. Jakhlon (27.0%) and Nilkanth (18.9%) were non-significant. Maximum total spore count was recorded for *Glomus I* (61), followed by *Glomus II* (29), *Acaulospora I* (4) and *Acaulospora II* (2). The poorest counts were in *Gigaspora* (1) and *Glomus mossae* (1). Total spore counts were 64 and 34 at Nilkhanth and Jakhlon, respectively.

Among Lasoda sites, maximum colonization index was recorded at NRCAF, silvipasture site (32.9%), followed by NRCAF, block plantation and Nareta (16.9). Maximum total spore count was recorded for *Glomus I* (75), followed by, *Glomus II* (36) and *Acaulospora I* (24). Poorest total count was in *Acaulospora II* (1) and *Gigaspora* (1). Among different Lasoda sites,

maximum spore count was in NRCAF, block plantation (77), followed by NRCAF, silvipasture site (60) and in Nareta village (0).

Among different soil types, maximum colonization index was recorded in lateritic soil (27.9%), which was significantly more than colonization in red (21.2%) and black soils (17.9). Maximum total spore count was recorded in lateritic soil (376), followed by black soil (221) and red soil (122).

Six cultures of *Glomus* sp. and one culture of *Acaulospora* were purified from trap cultures set to isolated VAM fungi from rhizosphere of Aonla, Ber, Chironji and Lasoda. These fungi were multiplied on maize roots and utilized in further studies. Characteristics of above mentioned VAM species have been summarized in Table 4.19.

Results on effect of inoculation of different VAM species on growth and P uptake of Aonla showed that shoot length was significantly increased by Glomus 1 and Glomus 4. Collar diameter was significantly increased by Glomus 1. Glomus 1, Glomus 6, Glomus 4 and Glomus 3 significantly increased fresh shoot weight, Glomus 1, Glomus 4, Acaulospora 1, Glomus 3 and Glomus 6 significantly increased dry shoot weight and Glomus 1, Glomus 6, Acaulospora 1, and Glomus 3 significantly increased dry root weight. Maximum phosphorus uptake per plant was recorded in Glomus 3 (97.197 mg), followed by Acaulospora 1 (72.383 mg) and Glomus 6 (57.977 mg), which were significantly superior to control. Glomus 1 was ranked as most efficient VAM fungi for Aonla, based on observations made on P uptake per plant, shoot dry weight and root dry weight, followed by Acaulospora 1 and Glomus 3 (Table 5.3).

In Ber, none of tested VAM fungi increased shoot length and collar diameter of Ber. Glomus 1 (48.07 g) and Glomus 6 (38.78 g) significantly increased shoot fresh weight. Glomus 3 (62.42 g), Glomus 4 (59.43 g) and Glomus 6 (57.90 g) significantly increased root fresh weight. Glomus 1 significantly increased dry shoot weight and Glomus 3, Glomus 6, Glomus 4 (22.37 g) and Glomus 1 significantly increased dry root weight. Maximum

phosphorus uptake per plant was recorded in *Glomus* 3 (75.897 mg) followed by *Glomus* 1 (68.507 mg) and *Glomus* 6 (64.537 mg), which were significantly superior to control. *Glomus* 3, *Glomus* 6 and *Glomus* 1 were found superior to other VAM fungi in enhancing seedling dry biomass and P uptake by Ber seedlings (Table 5.3).

Among tested VAM species *Glomus* 4 was found more effective in increasing biomass of Chironji in terms of shoot length, collar diameter, fresh and dry weight of shoot and root, *Glomus* 6, *Glomus* 1 and *Glomus* 3 also increased the shoot length, fresh and dry biomass of the tree species. *Acaulospora* 1 and *Glomus* 5 significantly increased collar diameter but these treatments were at par with control with respect to other tested parameters. *Glomus* 2 decreased the growth of Chironji, however the differences were not significant.

Glomus 4 and Glomus 5 significantly increased shoot length of Lasoda and no significant differences among different treatments were recorded in collar diameter. Glomus 4, Glomus 5 and Glomus 1 significantly increased fresh shoot weight and no significant difference were recorded in dry shoot weight, Glomus 2 and Glomus 4 significantly increased fresh root weight, Glomus 2, Glomus 3, Glomus 4 and Glomus 1 significantly increased dry root weight and all the treatments significantly increased P uptake per plant. Glomus 1 was ranked as most efficient VAM fungi for Lasoda, based on observations made on P uptake per plant, shoot dry weight and root dry weight, followed by Glomus 2 and Glomus 4.

Results on build up of VAM mycorrhizal colonization of different crops in different seasons (Rabi, Zaid and Kharif) showed that maize was a good host for isolated *Acaulospora* and *Glomus* species.

Bibliography

BIBLIOGRAPHY

- Abbott, L.K. and Robson, A.D. 1977 a. The distribution and abundance of vesicular arbuscular endophytes in some western Australian soils. *Aust. J. Bot.* 25:515-522.
- Abbott, L.K. and Robson, A.D. 1977 b. Growth stimulation of subterranean clover with vesicular arbuscular mycorrhizas. *Aust. J. Agri. Res.* 28:639-649.
- Abbott, L.K. and Robson, A.D. 1978. Growth of subterranean clover in relation to the formation of endomycorrhizas by introduced and indigenous fungi in a field soil. *New Phytol.* 81:575.
- Abbott, L.K. and Robson, A.D. 1981. Infectivity and effectiveness of vesicular arbuscular mycorrhizal fungi: effect of inoculum potential type. *Aust. J. Agric. Res.* 32:631-693.
- Abbott, L.K. and Robson, A.D. 1982. The role of vesicular arbuscular mycorrhizal fungi in agriculture and the selection of fungi for inoculation. *Aust. J. Agric. Res.* 33:389-408.
- Adholeya, A. and Singh, R. 2006. *Jatropha* for wasteland development: TERI's mycorrhiza technology. *In: Biofuels Towards a Green and Secure Energy Future* (ed. P.P. Bhojvoid). TERI, New Delhi, India. pp. 137-154.
- Aggangan, N.C., Korilla, E.B. and Cruz, R.E. de La. 1990. Screening for effectiveness of four VA mycorrhizal fungi on *Acacia auriculiformis* in infertile soil. *Sylvatrop 1987 Publication* 12(3&4):133-140.
- Ahiabor, B.D. and Hirata, H. 1994. Characteristic responses of three tropical legumes to the inoculation of two species of VAM fungi in Andosol soils with different fertilities. *Mycorrhiza* 5(1):63-70.
- Alexander, I.J. and Fairely, R.I. 1983. Effects of nitrogen fertilization on populations of fine roots and mycorrhizas in spruce humus. *Pl. Soil* 71:49-53.
- Ammani, K. and Rao, A.S. 1996. Effect of two arbuscular mycorrhizal fungi *Acaulospora spinosa* and *A. scrobiculata* on upland rice varieties. *Microbiological Research* 151(3):235-237.

- Asif, M., Khan, A.G., Khan, M.A. and Kuck, C. 1995. Growth response of wheat to shared root vesicular arbuscular mycorrhizae inoculum under field conditions. *In: Mycorrhizae: biofertilizer for the future* (eds. A. Adholeya and S. Singh). Proc. of the third national conference on mycorrhiza TERI, New Delhi, India, March 13–15, 1995. pp. 432–437.
- Atayese, M.O., Awotoye, O.O., Osonubi, O. and Mulonogoy, K. 1993. Comparison of the influence of vesicular arbuscular mycorrhiza on the productivity of hedgerow woody legumes and cassava at the top and the base of a hill-slope in alley cropping systems. *Biology and Fertility of Soils* 16(3):198-204.
- Aziz, T. and Habte, M. 1988 a. Influence of organic residue on vesicular arbuscular mycorrhizal symbiosis in *Leucaena leucocephala*. *Leucaena Research Reports* 9:106-108.
- Aziz, T. and Habte, M. 1988 b. Role of molybdenum in establishing mycorrhizal *Leucaena* in an eroded oxisol. *Leucaena Research Reports* 9:109-110.
- Aziz, T. and Habte, M. 1989 a. Influence of inorganic N on mycorrhizal activity, nodulation and growth of *Leucaena leucocephala* in an oxisol subjected to simulated erosion. *Communication in Soil Science and Plant Analysis* 20(3-4):239-251.
- Aziz, T. and Habte, M. 1989 b. The sensitivity of three vesicular arbuscular mycorrhizal species to simulated erosion. *Journal of Plant Nutrition* 12(7):859-869.
- Aziz, T., Habte, M. and Yuen, J.E. 1991. Inhibition of mycorrhizal symbiosis in *Leucaena leucocephala* by chlorothalonil. *Plant and Soil* 131(1):47-52.
- Bagyaraj, D.J. and Machado, C. 1996. Phosphorus concentration in soil solution optimum for mycorrhizal symbiosis in *Leucanea leucocephala*. *Annals of Forestry* 4(2):123-128.
- Bagyaraj, D.J., Manjunath, A. and Patil, R.B. 1979. Occurrence of vesicular arbuscular mycorrhizas in some tropical aquatic plants. *Trans. Br. Mycol. Soc.* 72:164-167.
- Bagyaraj, D.J. and Manjunath, A. 1980. Selection of suitable host for mass production of VA mycorrhizal inoculum. *Plant Soil* 55:495-498.

- Bagyaraj, D.J. and Rangaswami, G. 1972. Studies on the rhizosphere microflora of *Eleusine coracana* under the influence of foliar chemicals sprays. I. quantitative incidence of microorganisms. *Madras Agric. J.* 59:517.
- Bala, K., Rao, A.V. and Tarafdar, J.C. 1989. Occurrence of VAM association in different plant species of the Indian desert. *Arid Soil Research and Rehabilitation* 3(3):391-396.
- Bansal, M. and Mukerji, K.G. 1994. Positive correlation between VAM-induced changes in root exudation and mycorrhizosphere mycoflora. *Mycorrhiza* 5(1):39-44.
- Bansal. M., Mukerji, K.J. and Box, J.E. 1998. The role of endomycorrhizas in fine root litter degradation. *In: Root demographics and their efficiencies in sustainable agriculture, grasslands and forest ecosystem.* Proceeding of the 5th Symposium of the International Society of Root Research. Clemson university, South Carolina, USA, July 14-18, 1996. pp.393-401.
- Barbara, A. and Hetrick, D. 1984. Ecology of VA Mycorrhizal Fungi. *In: VA Mycorrhiza* (Eds. C.L. Powell and D.J. Bagyaraj). CRC Press, Florida. pp. 35-55.
- Bass Becking, L.G.M., Kaplan, I.R. and Moore, D. 1960. Limits of the natural environment in terms of pH and oxidation reduction potentials. *J. Geol.* 68:243-284.
- Benjamin, R.K. 1979. Zygomycetes and their spores. *In: The Whole Fungus* (ed. B. Kendricks). National Museums of Canada, Ottawa. pp. 573-616.
- Berch, S.M. 1986. Endogonaceae: Taxonomy, specificity, fossil record, Phylogeny. *In: Frontiers in Applied Microbiology* (eds. K.G. Mukerji, N.C. Pathak and V.P. Singh). India Print House, Lucknow. pp. 2:161-186.
- Besin, P.S., Gour, R.K., Jain, R.K., Dev, A. and Sengupta, L.K. 1996. VAM colonization in tree species planted in Cu, Al and coal mine of Madhya Pradesh with special reference to *Glomus mosseae*. *Mycorrhizal News* 8(1):9-11.
- Bevege, D.I. and Bowen, G. D. 1975. *Endogone* strain and host plant differences and development of vesicular arbuscular mycorrhizas. *In:* endomycorrhizas. (eds, F.E. Sander, B. Mosse and P.B. Tinker). Academic Press, London 77

- Bhatia, N.P., Sundari, K. and Adholeya, A. 1996. Diversity and selective dominance of vesicular arbuscular mycorrhizal fungi. *In: Concepts in Mycorrhizal Research* (ed. K.G. Mukerji). Kluwer Academic Publishers, Netherlands, pp 133-178.
- Black, R. and Tinker, P.B. 1979. The development of endomycorrhizal root systems. II. Effect of agronomic factors and soil conditions on the development of vesicular arbuscular mycorrhizal infection in barley and on the endophyte spore density. *New Phytol.* 83:401-413.
- Bonfante Fasolo, P. 1987. Vesicular arbuscular mycorrhizal fungus plant interactions at cellular level. *Symbiosis* 3:249-254.
- Boucher, A., Dalpe, Y. and Charest, C. 1999. Effect of arbuscular mycorrhizal colonization of four species of *Glomus* on physiological responses of maize. *Journal of Plant Nutrition* 22(4&5):783-797.
- Bowen, G.D. 1980. Mycorrhizal roles in tropical plants and ecosystems. *In: Tropical Mycorrhiza Research* (ed. P. Mikola). Oxford University Press, Oxford. pp. 165-190.
- Bowen, G.D. 1984. Tree roots and the use of soil nutrients. *In: Nutrition of Plantation Forests* (eds. G.D. Bowen and E.K.S. Nambiar). Academic Press, London. pp. 147-167.
- Bowen, G.D. and Rovira, A.D. 1976. Microbial colonization of plant roots. *Annu. Rev. Phytopathol.* 14:121-144.
- Cao, J.D., Tang, Y.G., Qin, S.M. and Hou, Y.R. 1995. Dual inoculation of Mimosaceae seedlings with vesicular arbuscular mycorrhizal fungi and *Rhizobium. In: Mycorrhizas for plantation forestry in Asia* (eds. M. Brundett, B. Dell, N. Malajczuk and Ming Quin, Gong). Proceeding of an international Symposium and Workshop. Kaiping, Guangdong Orovince, P.R. China. Nov.7-11, 1994. pp.119-121.
- Carling, D.E. and Bowen, M.F. 1980. Relative effect of vesicular arbuscular mycorrhizal fungi on the growth and yield of soybean. *J. Soil Sci. Am.* 44:528-523.
- Chandra, K.K. and Jamaluddin. 1999. Distribution of vesicular arbuscular mycorrhizal fungi in coal mine overburden dumps. *Indian Phytophathology* 52(3):254-258.

- Chaturvedi, O.P. and Pandey, I.B. 2000. Yield and economics of *Populus delfoides* G 3 marsh based intercropping systems in eastern India. *Forest Tree and Livelihood* 11:207-216.
- Clarke, C. and Mosse, B. 1981. Plant growth response to vesicular arbuscular mycorrhiza. XII. Field inoculation responses of barley at two soil levels. *New Phytol.* 87: 695-703.
- Clayton, J.S. and Bagyaraj, D.J. 1984. Vesicular arbuscular mycorrhizas in submerged aquatic plants of New Zealand. *Aquatic Botany* 19:251-262.
- Cooper, K.M. 1976. A field survey of mycorrhizas in New Zealand ferns. New Zealand J. Bot. 14:169-181.
- Costa, N.de.L., Dionisio, J.A. and Anghinoni, I. 1987. Effect of inoculation of endomycorrhizal fungi and source of phosphorus on growth of sudangrass and Leucaena. Agronomia Sulriograndense 23(1):65-73.
- Costa, N.de.L. and Paulino, V.T. 1990. Response of *Leucaena* to vesicular arbuscular mycorrhizal inoculation and phosphorus fertilization. *Leucaena Research Reports* 11:42-44.
- Costa, N.de.L., Paulino, V.T. and Veasey, E.A. 1992. Effect of phosphate fertilization and mycorrhizal inoculation on growth and phosphorus uptake of *Leucaena Leucaena Research Reports* 13:8-9.
- Costa, N.de.L., Paulino, V.T., Veasey, E.A. and Leonidas, F.de.C. 1992. Effect of vesicular arbuscular mycorrhiza and rock phosphate fertilization on growth, nodulation, nitrogen and phosphorus uptake of *Leucaena Leucaena Research Reports* 13:10-12.
- Daft, M.J., Chilvers, M.T. and Nicolson, T.H. 1980. Mycorrhizas of the Liliflorae. I. Morphogenesis of *Endymion nonscriptus* (L.) Garcke and its mycorrhizas in nature. *New Phytol*. 85:181-189.
- Daft, M.J. and El Giahmi, A.A. 1978. Effect of arbuscular mycorrhiza on plant growth. VIII. Effect of defoliation and light on selected hosts. *New Phytol.* 80:365-372.
- Daft, M.J., Hacskaylo, E. and Nicolson, T.H. 1975. Arbuscular mycorrhizas in plants colonizing coal spoils in Scotland and Pennsylvania. *In: Endomycorrhizas* (eds. F.E. Sanders, B. Mosse and P.B. Tinker). Academic Press, London. pp.561-580.

- Daft, M.J. and Nicolson, T.H. 1974. Arbuscular mycorrhizas in plants colonizing coal wastes in Scotland. *New Phytol*. 73:1129-1138.
- Daniels, B.A. and Trappe, J.M. 1980. Factors affecting spore germination of the vesicular arbuscular mycorrhizal fungus, *Glomus epigaeus*. *Mycologia* 72:457-471.
- Daniels, B.A. and Menge, J.A. 1981. Evaluation of the commercial potential of the vesicular arbuscular mycorrhizal fungus, *Glomus epigaeus*. New *Phytol*. 87: 345.
- Daniels, B.A., McCool, P.M. and Menge, J.A. 1981. Comparative inoculum potential of spores of six vesicular arbuscular mycorrhizal fungi. *New Phytol.* 89:385.
- Davis, E.A. and Young, J.L. 1985. Endomycorrhizal colonization of glasshouse grown wheat as influenced by fertilizer salts when banded or soil mixed. *Can. J. Bot.* 63:1196-1203.
- Devagiri, G.M., Dhiman, R.C., Singh, Y.P. and Patil, S.K. 2001. Seed source dependent variation in mycorrhizal colonization and nutrient uptake in *Dalbergia sissoo* seedling. *Journal of Tropical Forest Science* 13(2):246-257.
- Diederichs, C. 1992. Impact of tropical VA mycorrhizae on growth promotion of Cajanus cajan as influenced by P sources and P levels. In: Proceedings of the International Symposium on Management of Mycorrhizas in Agriculture, Horticulture and Forestry. (ed. D. Jasper). University of Western Australia, Nedlands, Australia, 28 September 2 October, 1992. pp. 55.
- Dixon, R.K., Garg, V.K. and Rao, M.V. 1993. Inoculation of *Leucaena* and *Prosopis* seedlings with *Glomus* and *Rhizobium* species in saline soil. *Arid soil Research and Rehabilitation* 7(2):133-144.
- Dixon, R.K., Garg, V.K. and Rao, M.V. 1994. Water relations and gas exchange of mycorrhizal *Leucaena leucocephala* seedlings. *Journal of Tropical Forest Science* 6(4):542-552.
- Douds, D.D., Galvez, L., Becard, G. and Kapulnik, Y. 1998. Regulation of arbuscular mycorrhizal development by plant host and fungus species in alfalfa. *New Phytologist* 138(1):27-35.
- Dowding, E.S. 1959. Ecology of Endogone. Trans. Br. Mycol. Soc. 42:449-457.

- Dugaya, D., Williams, A.J., Chandra, K.K., Gupta, B.N. and Banerjee, S.K. 1996. Mycorrhizal development and plant growth in amended coal mine overburden. *Indian Journal of Forestry* 19(3):222-226.
- Ferguson, J. J. 1981. Inoculum Production and Field Application of Vesicular Arbuscular Mycorrhizal Fungi, Ph.D. Thesis, University of California, Riverside.
- Fisher, R.A. and Yates, F. 1963. Statistical tables (sixth edition) for biological, agricultural and medical research. Longonan Group Limited, England.
- Frank, A.B. 1985. Uber die auf Werzelsymbiose beruhende Ernahrung gewisser Baume durch unterirdische Pilze. Ber. Dtsch. Bot. Ges. 3:128-145.
- Furlan, V. and Fortin, J.A. 1973. Formation of endomycorrhizae by *Endogone* calospora on Allium cepa under three different temperature regimes. Nat. Can. (Quebec) 100:467-477.
- Furlan, V. and Fortin, J.A. 1977. Effect of light intensity on the formation of vesicular arbuscular endomycorrhizas on *Allium cepa* by *Gigaspora calospora*. New Phytol. 79:335-340.
- Ganesan, V. and Mahadevan, A. 1994. Effect of mycorrhizal inoculation of cassava, elephant foot yam and taro. *Journal of Root Crops* 20(1):1-14.
- Ganesan, V., Ragupathy, S., Parthipan, B., Rani, D.B.R. and Mahadevan, A. 1991. Distribution of vesicular arbuscular mycorrhizal fungi in coal, lignite and calcite mine spoils of India. *Biology and Fertility of Soils* 12(2):131-136.
- Garret, H. E., Buck, L.E., Gold, M.A., Hardest, L.H., Kurt, W. B., Lassoie, J. P., Pearson, H. A. and Slusher, J. P. 1994. Agroforestry: an integrated land-use management systems for production and farmland conservation. USDA SCS 68-3A75-3-134. Washington, DC: US Department of Agriculture.
- Gaur, A. and Adholeya, A. 1994. Estimation of VAMF spores in soil: a modified method. *Mycorrhiza News* 6:10-11.
- Gaur, A., Adholeya, A. and Mukerji, K.G. 1998. A comparison of AM fungi inoculants using Capsicum and Polianthes in marginal soil amended with organic matter. *Mycorrhiza* 7(6):307-312.

- Gazey, C., Abbott, L. and Robson, A. 1992. Development of vesicular arbuscular (VA) mycorrhizas on clover by three species of *Acaulospora* in relation to effects on plant growth. *In: Proceedings of the International Symposium on Management of Mycorrhizas in Agriculture, Horticulture and Forestry* (ed. D. Jasper). University of Western Australia, Nedlands, Australia, 28 September 2 October, 1992. pp. 32.
- Gerdemann, J.W. 1968. Vesicular arbuscular mycorrhiza and plant growth. *Annu. Rev. Phytopathol.* 6:397-418.
- Gerdemann, J.W. 1975. Vesicular arbuscular mycorrhizae. *In: The Development and Function of Roots* (eds. J.G. Torrey and D.T. Glarkson). Academic Press, London. pp. 576-591.
- Gerdemann, J.W. and Nicolson, T.H. 1963. Spores of mycorrhizal *Endogone* species extracted from soil by wet sieving and decanting. *Tran. Br. Mycol. Soc.* 46:235-244.
- Gildon, A. 1981. The Influence of Vesicular Arbuscular Fungus on the Host Plant Uptake of Heavy Metals, Ph.D. thesis University of London.
- Gildon, A. and Tinker, P.B. 1983. Interaction of vesicular-arbuscular mycorrhiza infection and heavy metals in plants. I. The effect of heavy metals on the development of vesicular arbuscular mycorrhizas. *New Phytol.* 95:247-261.
- Giovannetti, M. and Mosse, B. 1980. An evaluation of techniques for measuring vesicular arbuscular mycorrhizal infection in roots. *New Phytol.* 84:489-500.
- Graham, J.H., Leonard, R.T. and Menge, J.A. 1981. Membrane-mediated decrease in root exudation responsible for phosphorus inhibition of vesicular arbuscular mycorrhiza formation. *Plant Physiol.* 68:548-552.
- Graham, J.H., Leonard, R.T. and Menge, J.A. 1982. Interaction of light intensity and soil temperature with phosphorus inhibition of vesicular arbuscular mycorrhiza formation. *New Phytol.* 91:683-690.
- Graw, D. and Rehm, S. 1977. Vesicular arbuscular mycorrhiza in den Fruhttragern von *Arachis hypogea*. L.Z. Acker Und Pflanzenbau 144:75-78.
- Green, N.E., Graham, S.O. and Schenck, N.C. 1976. The influence of pH on the germination of vesicular arbuscular mycorrhizal spores. *Mycologia* 68:929-934.

- Gurumurthy, S.B. and Sreenivasa, M.N. 2000. Occurrence and distribution of VAM fungi in the rhizosphere of five tree species grown under agroforestry system. *Environment and Ecology* 18(2):500-502.
- Gurumurthy, S.B., Sreenivasa, M.N., Kulkarni, J.H. and Nadagoudar, B.S. 1999. Screening and selection of an efficient VAM fungus for Shisham (*Dalbergia sissoo*). Karnatak Journal of Agriculture Sciences 12(1-4):88-92.
- Guissou, T., Ba, A.M., Ouadba, J.M., Guinko, S. and Duponnois, R. 1998. Responces of Parkia biglobosa (Jacq.) Benth, *Tamarindus indica* L. and *Zizyphus mauritiana* Lam. to vesicular arbuscular mycorrhizal fungi in a phosphorus deficient sandy soil. *Biology and Fertility of Soil*. 17(3):194-198.
- Habte, M. and Aziz, T. 1991. Relative importance of Ca, N and P in enhancing mycorrhizal activity in *Leucaena leucocephala* grown in an oxisol subjected to simulated erosion. *Journal of Plant Nutrition* 14(5):429-442.
- Habte, M. and Fox, R.L. 1989. Leucaena leucocephala seedling response to vesicular arbuscular mycorrhizal inoculation in soils with varying level of inherent mycorrhizal effectiveness. Biology and Fertility of Soils 8(2):111-115.
- Habte, M. and Manjunath, A. 1988. Influence of phenamiphos on the vesicular arbuscular mycorrhizal symbiosis in *Leucaena leucocephala*. *Biology and Fertility of Soils* 5(4):313-316.
- Habte, M. and Manjunath, A. 1991. Categories of vesicular arbuscular mycorrhizal dependency of host species. *Mycorrhiza* 1(1):3-12.
- Habte, M. and Manjunath, A. 1992. Initial and residual toxicity of soil applied Thiram on the vesicular arbuscular mycorrhizal symbiosis. *Mycorrhiza* 2(1):25-31.
- Habte, M. and Musoko, M. 1994. Changes in the vesicular arbuscular mycorrhizae dependency of *Albizia ferruginea* and *Enterolobium cyclocarpum* in response to soil phosphorous concentration. *Plant Nutr.* 17:1769-1780.
- Habte, M., Fox, R.L., Aziz, T., E. Swaify and EL Swaify, S.A. 1988. Interaction of vesicular arbuscular mycorrhizal fungi with erosion in an oxisol. *Applied and Environmental Microbiology* 54(4):945-950.

- Hall, I.R. 1977. Species and Mycorrhizal infections of New Zealand endogonaceae. *Trans. Br. Mycol. Soc.* 66: 341-356.
- Hall, I.R. 1984. Taxonomy of VA mycorrhizal fungi. *In: VA mycorrhiza* (eds. C.L. Powell and D.J. Bagyaraj). CRC Press, Boca Raton, FL. pp. 57-94.
- Hall, I.R. and Abbott, L.K. 1983. Photographic slide collection illustrating features of Endogonaceae. *Bull. Br. Mycol. Soc.* 17:54-55.
- Harinikumar, K.M. and Bagyaraj, D.J. 1995. Spread of vesicular arbuscular mycorrhizal fungal hyphae in soil. *Microbiological Research* 150(1):77-80.
- Harley, J.L. 1969. The Biology of Mycorrhiza, 2nd ed. Leonard Hill London.
- Hayman, D.S. 1975. The occurrence of mycorrhiza in crops as affected by soil fertility. *In: Endomycorrhizas* (eds. F.E. Sanders, B. Mosse and P.B. Tinker). Academic Press, London. pp. 495-509.
- Helal, M., Upenov, A. and Hakim, N. 1998. Uptake of heavy metal by mycorrhizal roots of Leucanea leucocephala. In: Einfluss von erzeugung und Verarbeitung auf die qualitat landwirtschaftlichen Produkte. Vortrage zum generalthema des 110 VDLUFA-Kongresses, Giessen, Germany, September 14-18, 1998. pp. 577-580.
- Hepper, C.M. 1979. Germination and growth of *Glomus caledonius* spores: The effects of inhibitors and nutrients. *Soil. Biol. Biochem.* 11:269-277.
- Hepper, C.M. and Smith, G.A. 1976. Observations on the growth of *Endogone* spores. *Trans. Br. Mycol. Soc.* 66:189-194.
- Hiltner, L. 1904. Uber neure Erfahrungen und Probleme auf dem Gebiet der Bodenbakteriologie und unter besonderer Beruksichtigung der Grundingung und Brache, Arb. Dtsch. Landwirtsch. Gesellschaftswiss. 98:59-78.
- Ikram, A., Mahmud, A. W. and Othman, H. 1993. Growth response of *Hevea brasiliensis* seedling root stock to inoculation with vesicular arbuscular mycorrhizal fungal species in steam sterilised soil. *Journal of National Rubber Research*. 5(3): 231-242.
- Jackson, M.L. 1973. Soil Chemical Analysis. Prentice Hall of India Pvt. Ltd., New Delhi.

- Jagpal, R. and Mukerji, K.G. 1991. VAM fungi in reforestation. *In: Plant Root and their Environment* (eds. B.L. McMichael and H. Persson). Proceeding of an ISRR Symposium. Uppsala, Sweden, August 21-26, 1988. pp. 309-313.
- Jaizme Vega, M.C. and Azcon, R. 1995. Responses of some tropical and subtropical cultures to endomycorrhizal fungi. *Mycorrhiza* 5(3):213-217.
- Jamaluddin, Chandra, K.K. and Kumar, K. 1998. Effect of fungicides on colonization and development of VAM in *Dalbergia sissoo*. *Indian Forester* 124(8):650-662.
- Jamaluddin, Chandran, K.K. and Malakar, G.H. 2001. Studies on VAM fungi associates with tree species planted in a sludge garden at the Ballarpur Paper Mills, Maharashtra. *Mycorrhiza News* 13(4):10-12.
- Janos, D.P. 1983. Tropical mycorrhizas. *In: Tropical Rain Forest: Ecology and Management* (eds. S.L. Sutton, T.C. Whitmore and A.C. Chadwick). Blackwell Scientific Publications, Oxford. pp. 327-345.
- Jasper, D.A., Abott, L.K. and Robson, A.D. 1989. Acacias respond to additions of phosphorus and to inoculation with VA mycorrhizal fungi in soils stock piled during mineral sand mining. *Plant and Soil* 115:99-108.
- Jasper, P.A., Robson, A.D. and Abbott, L.K. 1979. Phosphorus and the formation of vesicular arbuscular mycorrhizas. *Soil Biol. Biochem.* 11:501-505.
- Jensen, A. and Jakobsen, I. 1980. The occurrence of vesicular arbuscular mycorrhiza in barley and wheat grown in some Danish soils with different fertilizer treatments. *Pl. Soil* 55:403-414.
- Johnson, C.R. and Michelini, S. 1974. Effect of mycorrhizae on container grown *Acacia* Proc. Of the Florida State Hort. Soc. 87:520-522.
- Joner, E.J. and Jakobsen, I. 1994. Contribution by two arbuscular mycorrhizal fungi to P uptake by cucumber (*Cucumis sativus* L) from (32) P-labelled organic matter during mineralization in soil. *Plant Soil* 163(2):203-209.
- Kalavathi, B.P., Santhanakrishnan, P. and Divya, M.P. 2000. Effect of VA mycorrhizal fungus and phosphorus solubilising bacteria in neem. *Indian Forester* 126(1):67-70.
- Kaushik, J.C. and Dabas, P. 2003. Interaction between VAM fungi, phosphorus fertilizer and water stress application on nodulation in

- Acacia nilotica (L.) Del. and Dalbergia sissoo Roxb. Forage Research 28(4):220-222.
- Kaushik, J.C., Dabas, P. and Kumar, R. 2000. Impact of *Glomus mosseae* inoculation on root pathogen in *Acacia nilotica* and *Dalbergia sissoo* seedlings. *Indian Journal of Forestry* 3(3):238-240.
- Kaushik, J.C. and Kaushik, N. 1995. Interaction between vesicular arbuscular mycorrhizal and Rhizobium and their influence on *Albizia lebbek* (L.) Benth. *In: Mycorrhiza Biofertilizer for future* (eds. Adholeya and Singh). TERI, New Delhi, India. pp.212-215.
- Kendrick, B. and Berch, S. 1985. Mycorrhizae: Applications in agriculture and forestry. *In: Comprehensive Biotechnology* (ed. C.W. Robinson). Pergamon Press, Oxford. pp. 4:109-150.
- Khan, A.H. 1974. The occurrence of mycorrhizas in halophytes and xerophytes and of *Endogone* spores in adjacent soil. *J. Gen. Microbiol.* 81:7-14.
- Kitson, R.E. and Mellon, M.G. 1944. Colorimetric determination of phosphorus as molybdivanado phosphoric acid. *Ind. Eng. Chem. Anal. Ed.* 16:379-383.
- Koffa, S.N., Cruz, R.E. de la and De La Cruz, R.E. 1995. Screenhouse performance of VAM inoculated seedling of *Leucaena leucocephala* in a phosphorus deficient and aluminium sulphate treated medium. *New Forests* 9(3):273-279.
- Koske, R. E. 1987. Distribution of VA mycorrhizal fungi along a latitudinal tempeature gradient. *Mycologia* 79:55-68.
- Krishna, K.A., Shetty, K.G. Dart, P.J. and Andrews, D. J. 1985. Genotype dependent variation in mycorrhizal colonization and response to inoculation of pearl millet. *Plant and Soil* 86:113-125.
- Kumar, A., Shukla, A., Hashmi, S. and Tewari, R.K. 2007. Effect of tree on colonization of intercrops by vesicular arbuscular mycorrhizae in agroforestry system. *Indian Journal of Agriculture Sciences* 77(5):291-298.
- Kumar, A. and Bisaria, A.K. 1999. Studies on vesicular arbuscular mycorrhizae. *Annual Report, National Research Centre for Agroforestry*, Jhansi. pp. 11-12.

- Kumar, A. and Bisaria, A.K. 2000. Studies on vesicular arbuscular mycorrhizae. *Annual Report, National Research Centre for Agroforestry*, Jhansi. pp. 9-12.
- Kumar, P.P., Reddy, S.R. and Reddy, S.M. 1999. Interaction of some agrochemicals and VAM fungi on growth of two agroforestry tree species in nursery. *Journal of Mycology and Plant Pathology* 29(3):385-388.
- Kumar, P.P., Reddy, S.R., Reddy, S.M. and Kumar, P. 2000. Mycorrhizal dependency of some agroforestry tree species. *Indian Forester* 126(4):397-402.
- Lambert, D.H. and Cole, H. Jr. 1980. Effects of mycorrhizae on establishment and performance of forage species in mine spoil. *Agron. J.* 72:257-260.
- Lamont, B. 1972. The morphology and anatomy of proteoid roots *In:* the genus. *Hakea. Aust. J. Bot.* 20:155-174.
- Le Tacon, F., Skinner, F.A. and Mosse, B. 1983. Spore germination and hyphal growth of a vesicular arbuscular mycorrhizal fungus, *Glomus mosseae* (Gerdemann and Trappe), under decreased oxygen and increased carbon dioxide concentration. *Can. J. Microbiol.* 29:1280-1285.
- Maluf, A.M., Silveira, A.P.D. Da. and Melo, I.S.de. 1988. The influence of liming and vesicular arbuscular mycorrhiza on the development of aluminium tolerant and intolerant cultivaters of *Leucaena leucocephala*. Revista Brasileria de ciencia do solo 12(1):17-23.
- Mandal, B.S. and Kaushik, J.C. 1994. Effect of VAM inoculations of growth and development of *Acacia nilotica* (L.) Willd. Ex. del. *Annals of Biology* (Ludhiana) 10(2):264-267.
- Manjunath, A. and Habte, M. 1988. Development of vesicular arbuscular mycorrhizal infection and the uptake of immobile nutrient in *Leucaena leucocephala*. *Plant and Soil* 106(1):97-103.
- Manjunath, A. and Habte, M. 1991. Rate variables association with P uptake, utilization and growth of mycorrhizal and nonmycorrhizal *Leucaena leucocephala*. *Journal of Plant Nutrition* 12(6):755-768.
- Manjunath, A. and Habte, M. 1991. Relationship between mycorrhizal dependency and rate variables associated with uptake, utilization and

- growth. Communication in Soil Science and Plant Analysis 22(13-14):1423-1437.
- Manjunath, A. and Habte, M. 1992. External and internal P requirement of plant species differing in their mycorrhizal dependency. *Arid Soil Research and Rehabilitation* 6(4):271-284.
- Manjunath, A., Hue, N.V. and Habte, M. 1989. Response of *Leucaena leucocephala* to vesicular arbuscular mycorrhizal colonization and rock phosphate fertilization in an oxisol. *Plant and Soil* 114(1):127-133.
- Manjunath, A., Mohan, R., Raj, J. and Bagyaraj, D.J. 1981. Vesicular arbuscular mycorrhizas in cultivars of rice. J. Soil. Biol. Ecol. 1:1-4.
- Manjunath, A.R. 1990. Host related determinants of vesicular arbuscular mycorrhizal dependency in selected species of *Leucaena* and *Sesbania*. Dissertation Abstracts International B, Science and Engineering 51(2):576-577.
- Mason, E. 1928. Note on the presence of mycorrhiza in the roots of salt marsh plants. *New Phytol.* 27:193-195.
- Mathur, R.S. and Sharma, K.K. 1983. Populus in India. Indian Forester. 109:591-631.
- Mathur, N. and Vyas, A. 1996. Relative efficiency of different VAM fungi on growth and nutrient uptake in *Zizyphus mauritiana*. *Indian Journal of Forestry* 19(2):129-131.
- McGraw, A.C. and Schenck, N.C. 1981. The mycorrhizal relationship in tomato as influenced by fungal species, inoculum density, and cultivar. *In: Proceedings of the Fifth North American Conference on Mycorrhizae* (ed. J.A. Fortin). University of Laval, Quebec, Canada, August 16-21, 1981. pp. 83.
- Mehrotra, A., Mehrotra, M.D. and Mehrotra, A. 2000. Studies on VAM fungi of forest tree. Associates of *Gigasporaceous* fungi, an important feature of some *Acacia* species. *Indian Journal of Forestry* 23(1):20-27.
- Mehrotra, M.D., Mehrotra, Arushi and Mehrotra, A. 1999. Suitability of potting mixture for VAM infection and spore population in root trainer raised seedlings. *Indian Journal of Forestry* 22:1-2.
- Menge, J.A. 1984. Inoculum production. *In*: VA Mycorrhiza (eds. C.L. Powell and D.J. Bagyaraj). CRC Press, Inc., Boca Raton, FL. pp. 188-199.

- Menge, J.A., Davis, R.M., Johnson, L.V. and Zentmeyer, G. 1978. Mycorrhizal fungi increase growth and reduce transplant injury in Avocado. *Calif. Agric.* 32(67):433-435.
- Menge, J.A., Steirle, D., Bagyaraj, D.J., Johnson, E.L.V. and Leonard, R.T. 1978. Phosphorus concentrations in plants responsible for inhibition of mycorrhizal infection. *New Phytol.* 80:575-578.
- Michelsen, A. and Rosendahl, S. 1990. The effect of mycorrhizal fungi, phosphorus and drought stress on the growth of *Acacia nilotica* and *Leucaena leucocephala* seedlings. *Plant and Soil* 124(1):7-13.
- Miller, D.D., Bodmer, M. and Schuepp, H. 1989. Spread of endomycorrhizal colonization and effects on growth of apple seedlings. *New Phytologist* 111(1):51-59.
- Mohan, V. 2000. Studies of endomycorrhizal fungi in association with economically important species of Indian arid zone. *Advances in Forestry Research in India* 23:184-203.
- Mohan, V., Verma, Neelam, Singh, Y.P. and Verma, N. 1995. Distribution of VAM fungi in nurseries and plantation of neem (*Azadirachta indica*) in arid zone of Rajasthan. *Indian Forester* 121(11):1069-1076.
- Mosse, B. 1972. The influence of soil type and *Endogone* strain on the growth of mycorrhizal plants in phosphate deficient soils. *Rev. Ecol. Biol. Soil* 9:529-537.
- Mosse, B. and Bowen, G.D. 1968. The distribution of Endogone spores in some Australian and New Zeland soils and in the experimental field soil at Rothamsted. *Trans. Br. Mycol. Soc.* 51:485-492.
- Mosse B, Stribley, D.P. and Le Tacon F. 1981. Ecology of mycorrhizae and mycorrhizal fungi *In: Advances in Microbial Ecology* (ed. M. Alexander). Plenum Press, New York. pp. 5:137-209.
- Mukerji, K.G. 1996. *In: 'Advances in Botany'* (ed. K. G Mukerji). APH Publishing crop., New Delhi, India. pp. 212-218.
- Mukerji, K.G., Chamola, B.P., Kaushik, A., Sarwar, N. and Dixon, R.K. 1996. Vesicular arbuscular mycorrhiza: Potential Bio-fertilizer for nursery raised multipurpose tree species in tropical soils. *Annals of Forestry* 4(1):12-20.

- Nemec, S. 1979. Growth of *Citrus jambhiri* as affected by single and combined incocula of three *Glomus* species. *In: Proceedings of the Fourth North American Conference on Mycorrhiza*. Colorado State University, Fort Collins, Colorado, USA, June 24-28, 1979.
- Nemec, S. 1978. Response of 6 Citrus rootstocks to 3 species of Glomus, Proc. Fla. State Hortic. Soc. 91:10-14.
- Nemec, S. 1987. VA mycorrhizae in horticultural systems. *In: Ecophysiology of VA Mycorrhizal Plants* (ed. G.R. Safir). CRC Press, Inc., Boca Raton, FL. pp. 193-211.
- Nye, P.H. 1977. The rate limiting step in plant nutrient absorption from soil, *Soil sci.* 123:292.
- Obura, R.K., Skipper, H.D. and Wagner, S.C. 1987. Effect of VAM fungi on cowpea under two levels of soil phosphorus *In: Proceedings of the Seventh North American Conference on Mycorrhiza* (eds. D.M. Sylvia, L.L., Hung and J.H. Graham). University of Florida, Florida, May 3-8, 1987. pp.364
- Olsen, S.R., Cole, C.V., Watanabe, F.S. and Dean, L.A. 1954. *Estimation of Available Phosphorus in Soils by Extraction with Sodium bi-carbonate*. US Department of Agriculture, Washington DC, Circular 939.
- Osonubi, O., Mulongoy, K., Awotoye, O.O., Atayese, M.O. and Okali, D.U.U. 1991. Effect of ectomycorrhizal and vesicular arbuscular mycorrhizal fungi on drought tolerance of four leguminous woody seedlings. *Plant and Soil* 136(1):131-143.
- Owusu Bennoah, E. and Mosse, B., 1979. Plant growth responses to vesicular arbuscular mycorrhiza. XI. Field inoculation responses in barley, lucerne and onion. *New Phytol.* 83:671-679.
- Pahwa, M.R. 1995. Effect of inoculation of *Rhizobium*, VAM fungi and phosphate solubilizing bacteria on nodulation and seedling vigour of *Leucanea leucocephala*. Range Management and Agroforestry 16(2):129-131.
- Pande, Munish, Tarafdar, J.C., Gupta, G.N. and Pande, M.1999. Vesicular arbuscular mycorrhizal infection in arid zone trees of agroforestry systems. *Journal of the Indian Society of Soil Science* 47(1): 54-57.

- Pande, Munish., Tarafdar, J.C. and Pande, M. 2002. Effect of phosphorus, salinity and moisture on VAM fungal association in Neem (*Azadirachta indica* Linn.). Symbiosis Rehoval 32(3):195-209.
- Parke, J.L. and Linderman, R.G. 1980. Association of vesicular arbuscular mycorrhizal fungi with the moss *Funaria hygrometrica*. Can. J. Bot. 58:1898-1904.
- Parkinson, D. 1967. Soil microorganisms and plant roots *In: Soil Biology* (eds. A. urges and F. Raw). Academic Press, London, 449.
- Paroha, S., Chandra, K.K. and Tiwari, K.P. 2000. Synergistic role of VAM and *Azotobacter* inoculation on growth and biomass production in forestry species. *Journal of Tropical Forestry* 16(1):12-14.
- Pathak, R.K. 2000. Banjar bhumi hetu aonla ek verdan. *In:* Krishivanki Dwara Prakrithik Sansadhanon Ka Prabandhan Evam Paryavaran Samraksha (eds. K.S. Dadwal and K.R. Solanki). National Research Centre for Agroforestry, Jhansi. pp. 111-115.
- Phavaphur Anon, L., Davies, F.T. Jr. and Duray, S.A 1996. Growth, root alteration and nutrient uptake of neem tree (*Azadirachta indica* A. Juss) seedlings in response to vesicular arbuscular mycorrhizal fungi and phosphorus nutrition. *International Tree Crops Journal* 9(1):59-67.
- Phillip J.M. and Hayman, D.S. 1970. Improved procedure for clearing roots and staining parasitic and vesicular arbuscular mycorrhizal fungi for rapid assessment of infection. *Trans. Br. Mycol. Soc.* 55:158-161.
- Plenchette, C., Fortin, J. A. and Furlan, V. 1983. Growth responses of several plant species to mycorrhizae in a soil of moderate P fertility. I Mycorrhizal dependency under field conditions. *Plant and Soil* 70:199-209.
- Pokhriyal, T.C., Kamala, Udiyal, Chaukiyal, S.P., Thapar, H.S. and Udiyal, K. 1992. Effect of VAM inoculation on growth and nitroginase activity in *Albizia lebbeck* (Linn.) Benth. *Van Vigyan* 30(3-4):123-126.
- Ponnamperuma, F.N. 1972. The chemistry of submerged soils. Adv. Agron. 24:29-96.

- Ponton, F., Piche, Y., Parent, S. and Caron, M. 1990. Use of vesicular arbuscular mycorrhizae in Boston fern production. II. Evaluation of four inocula. *Horticultural Science* 25(4):416-419.
- Porter, W.M. 1979. The "Most Probable Number" method for enumerating infective propagules of vesicular arbuscular mycorrhizal fungi in soil. *Aust. J. Soil Res.* 17:515-519.
- Porter, W.M., Abbott, L.K. and Robson, A.D. 1978. Effect of rate of application of superphosphate on populations of vesicular arbuscular endophytes. *Aust. J. Exp. Agric. Anim. Husb.* 18:573-578.
- Powell, C.L. 1976. Mycorrhizal fungi stimulate clover growth in New Zealand hill country soils, Nature (London). 264:436.
- Powell, C.L. 1981. Effect of inoculum rate on mycorrhizal growth responses in pot grown onion and clover. *Plant soil* 62:231.
- Powell, C.L., Metcalfe, D.M., Buwalda, J.G. and Waller, J.E. 1980. Phosphate response curves of mycorrhizal and non mycorrhizal plants. II. Responses to rock Phosphates. N.Z.J. Agric. Res. 23: 477.
- Puthur, J.T., Prasad, K.V.S.K., Sharmila, P. and Saradhi, P.P. 1998. Vesicular arbuscular mycorrhizal fungi improve establishment of micro propagated *Leucaenea leucocephala* plantlets. *Plant Cell Tissue and Orange Culture* 53(1):41-47.
- Rahangdale, R. and Gupta, N. 1998. Selection of VAM inoculants for some forest tree species. *Indian Forester* 124(5):331-341.
- Raizada, A., Rao, M.S.R.M. and Jayaram, N.S. 1998. Growth of *Albizia lebbeck* Benth. Inoculated with VA mycorrhiza and *Rhizobium* in eroded mine soils of semiarid India. *Indian Journal of Soil Conservation* 26(2):122-128.
- Rajan, S.K., Reddy, B.J.D. and Bhagyaraj, D.J. 2000. Screening of arbuscular mycorrhizal fungi for their symbiotic efficiency with *Tectona grandis*. Forest Ecology and Management 126(2):91-95.
- Rajshekhara, E., Sreenivasa, M.N. and Bhat, R.S. 1989. Effect of cropping system on vesicular arbuscular mycorrhizal development in red gram and sunflower. *Karnataka Journal of Agricultural Sciences* 2(3):231-233.
- Ramana, B.V. and Babu, R.S.H. 1999. Response of onion (Allium cepa) to inoculation of VAM fungi at different levels of phosphorus. In:

- Proceedings of the National Conference on Mycorrhiza (ed. S. Singh). Bhopal, India, 5-7 March, 1999.
- Rani, V. and Bhaduria, S. 2001. Vesicular arbuscular mycorrhizal association with some medicinal plants growing on alkaline soil of Mainpuri district, Uttar Pradesh. *Mycorrhizal News* 13(2):12-14.
- Rao, V.U. and Rao, A.S. 1996. Response of blackgram (*Phaseolus radiatus*) and greengram (*P. mungo*) to inoculation with vesicular-arbuscular mycorrhizal fungus under different sources of phosphorus fertilizer. *Indian Journal of Agricultural Sciences* 66(1):613-616.
- Read, D.J. 1991. mycorrhizas in ecosystem *In: changes of atmospheric chemistry and effects on forest Ecosystem*. A rook experiment without roof (eds. Reinhard F. Hutt and Klaus Bellmani) kluwer academic Publishers, *Experientia* 47:376-391.
- Redhead, J.F. 1975. Endotrophic mycorrhizas in Nigeria: Some aspects of the ecology of the endotrophic mycorrhizal association of Khaya grandifolia C.D.D. In: Endomycorrhizas (eds. F.E. Sanders, B. Mosse and P. B. Tinker). Academic Press, London. pp. 447-459.
- Redhead, J.F. 1977. Endotrophic mycorrhizas in Nigeria. Species of the Endogonaceae and their distribution. *Trans. Br. Mycol. Soc.* 69:275-280.
- Reena, J. and Bagyaraj, D.J. 1990. Response of *Acacia nilotica* and *Calliandra calothysus* to different mycorrhizal fungi. *Arid Soil Research and Rehabilitation* 49(4):261-268.
- Reeves, F. B., Wagner, D., Moorman, T. and Kiel, J. 1979. The role of endomycorrhizae in revegetation practices in the semi-arid west. I. A comparison of incidence of mycorrhizae in severely disturbed and natural environments. *Am. J. Bot.* 66:6-13.
- Reid, C.P.P. and Bowen, G.D. 1979. Effects of soil moisture on VA mycorrhiza formation and root development in *Medicago*. *In: The Soil Root Interface* (eds. J.L. Harley and R.S. Russell). Academic press, London. p. 211.
- Reid, R.K., Parker, W.C., Mitchell, R.J., Garrett, L.C., Hundersen, G.S. and Cox, G.S. 1988. Vesicular arbuscular mycorrhizal inferences on growth and aluminium tolerance of sugar maple seedlings. University of British Colombia Publication, Canada, pp. 306-315.

- Richards, L.A. 1954. Diagnisis and improvement of saline and alkali soils. USDA Handbook No. 60.
- Rives, C.S., Bajwa, M.I. and Liberta, A.E. 1980. Effects of topsoil storage during surface mining on the viability of VA mycorrhiza. *Soil Sci.* 129:253-257.
- Rodriguez, G.A.M., Hurtado, M. and Sanchez de Prager, M. 1995. Inoculation of granadilla *Passiflora ligularis* L. with VAM. *Acta Agronomica*, *Universidad Nacional de Colombia* 45(1):89-98.
- Rovira, A.D. 1979. Biology of soil-root interface. *In: The Soil-Root Interface*. (eds., J.L. Warley and S.R. Russel). Academic Press, London 145-160.
- Rovira, A.D. and McDougall, B.M. 1967. Microbiological and biochemical aspects of the rhizosphere. *In: Soil Biochemistry* (eds. McLaren, A.D. and Peterson, G.H.). Marcel Dekker, New York. pp.1:417-493.
- Safir, G.R., Boyer, J.S. and Gerdemann, J.W. 1971. Nutrient status and mycorrhizal enhancement of transport in soybeans. *Plant Physiol*. 49:700-703.
- Saif, S.R. 1981. The influence of soil aeration on the efficiency of vesicular arbuscular mycorrhizae. I. Effect of soil oxygen on the growth and mineral uptake of *Eupatorium odoratum* L. inoculated with *Glomus macrocarpus*. New Phytol. 88:649-659.
- Sanders, F. E., Tinker, P.B., Black, R.L.B. and Palmerely, S.M. 1977. The development of endomycorrhizal root systems. I. Spread of infection and growth promoting effects with four species of vesicular arbuscular endophyte. *New phytol.* 78:257-268.
- Schenck, N.C., Graham, S.O. and Green, N.E. 1975. Temperature and light effects on contamination and spore germination of vesicular arbuscular mycorrhizal fungi. *Mycologia* 67:1189-1192.
- Schenck, N.C. and Perez, Y. 1987. Manual for the identification of VA Mycorrhizal Fungi. University of Florida, Gainesville, Florida, USA. pp. 1-245.
- Schenck, N.C. and Perez, Y. 1990. Manual for the identification of VA Mycorrhizal Fungi. University of Florida, Gainesville, Florida, USA. pp. 11-13.

- Schenck, N.C. and Schroder, V.N. 1974. Temperature response of Endogone mycorrhiza on soybean roots. *Mycologia* 66:600-605.
- Schonbeck, F. 1979. Endomycorrhiza in relation to plant disease. *In: Soil Born Plant Pathogens* (eds. Schippers and Gams). Academic Press, London. pp. 271-280.
- Secilia, J. and Bagyaraj, D.J. 1994. Selection of efficient vesicular arbuscular mycorrhizal fungi for wetland rice. A preliminary screen in mycorrhizas 4:265-268.
- Selvaraj, S., Prabhakaran, J., Mariappan, S., Ravi, K.B. and Arjunam, G. 1995. Signification of Rhizobia and endomycorrhizae on tree plantation nursery in alfisol. *In: Mycorrhiza: Biofertilizer for future* (eds. Adholeya and Singh). TERI, New Delhi, India. pp. 274-278.
- Selvaraj, T., Kannan, K. and Lakshminarasimhan, C. 1986. Vesicular arbuscular mycorrhizal fungi in roots and scale-like leaves of *Canna indica* L. (Cannaceae). *Curr. Sci.* 55:728-730.
- Sheikh, N.A., Saif, S.R. and Khan, H.G. 1975. Ecology of *Endogone*. II. Relationship of *Endogone* spore population with chemical soil factors. *Islamabad J. Sci.* 2:6-9.
- Sieverding, Ewald. 1991. Vesicular Arbescular Mycorrhizae Management in Tropical Agroforestry. Federal Republic of Germany.
- Singh, C.S. and Kapoor, A. 1989. Effect of seed inoculation with yeast on root colonization by native vesicular arbuscular mycorrhizal (VAM) fungi and symbiotic parameters of legumes under potted soil conditions. *Zentralblatt fur Microbiologie* 144(6):385-388.
- Singh, C.S., Kapoor, A. and Wange, S.S. 1991. The enhancement of root colonization of legumes by vesicular arbuscular mycorrhizal (VAM) fungi through the inoculation of the legume seed with commercial yeast (Saccharomyces cerevisiae). Plant and Soil 131(1):129-133.
- Singh, L. 1987. Practical agricultural chemistry and soil science. SMPS, Dehra Dun, India.
- Singh, S. 2001. Mycorrhizal dependency, Part I: Selection of efficient mycorrhizal fungi. *Mycorrhiza News* 13(1):2-16.

- Siqueira, J.O., Hubbell, D.H. and Schenck, N.C. 1982. Spore germination and germ tube growth of a vesicular arbuscular mycorrhizal fungus *in vitro*. *Mycologia* 74:952-959.
- Sivaprasad, P., Sulochana, K.K. and Nair, S.K. 1990. Comparative efficiency of different VA mycorrhizal fungi on cassava (*Manihot esculenta* Crantz) *Journal of Root Crops* 16(1):39-40.
- Smith, S. E. and Walker, N. A. 1981. A quantitative study of mycorrhizal infection in *Trifolium*: separate determinations of the rates of infection and of mycelial growth. *New Phytol*. 89:225-240.
- Soedarjo, M. and Habte, M. 1993. Vesicular arbuscular mycorrhizal effectiveness in an acid soil amended with fresh organic matter. *Plant and Soil* 149(2):197-203.
- Sparling, G.P. and Tinker, P.B. 1978. Mycorrhizal infection in Pennine grassland. I. Leaves of infection in the field. J. Appl. Ecol. 15:943-950.
- Sreenivasa, M.N. and Bagyaraj, D.J. 1988. Suitable level of zinc, copper and manganese for mass production of the vesicular arbuscular mycorrhizal fungus, *Glomus fasciculatum. Proc. Indian Acad. Sci.* 98:135-138.
- Sreenivasa, M.N. and Bagyaraj, D.J. 1989. Suitable form and level of phosphorus for mass production of the VA mycorrhizal fungus, *Glomus fasciculatum*. *Zbl. Microbiol*. 144:34-36.
- Srinivas, P., Rao, M.S., Reddy, S.R. and Reddy, S.M. 2001. Dynamics of VAM fungi of Godavari belt forests. *In: Perspective in biotechnology* (eds. S.M. Redy, D. Rao and Vidyavati). Proc. of a National Symposium. Warangal, India. Feb 26-27, 1999. pp. 23-30.
- Srinivasan, D., Muthukumar, T. and Udaiyan, K. 1996. Influence of effluent irrigation on VA mycorrhizae. *Indian Journal of Microbiology* 36(1):37-40.
- Sumana, D.A. and Bagyaraj, D.J. 1998. Selection of efficient VA mycorrhizal fungi for *Dalbergia latifolia*. Annals of Forestry 6(2):186-190.
- Sumana, D.A. and Bagyaraj, D.J. 1999. Selection of efficient mycorrhizal fungi for inoculating neem. (ed. S. Singh). Proceedings of the National Conference on Mycorrhiza. Bhopal, India. March 5-7, 1999.
- Sumana, D.A., Bagyaraj, D.J. and Nair, K.S.S. 1993. Growth stimulation of Delbergia sissoo by selected VA mycorrhizal fungi. *In: Impact of*

- diseases and insect pests in tropical forests. (eds. J.K. Sharma and R.V. Verma) Proc. of the IUFRO Symposium Peechi, India, November 23-26, 1993. pp. 246-251.
- Suvarna, C.V., Jayasheela, N. and Mamatha, G. 2002. Effect of dual inoculation of *Rhizobium* and *Glomus macrocarpum* on *Albizia lebbeck*. *Indian Journal of Forestry* 25(3-4):323-325.
- Taber, R.A., Smith, O.D., Smith, D.H., Pettit, R.E., Neck, J.S., Rajapakse, S. and Harman, W.F. 1987. Growth response of *Arachis hypogaea* to field inoculation with vesicular-arbuscular endomycorrhizal fungi. (eds. D.M. Sylvia, L.L. Hung and J.H. Graham). Proceedings of the Seventh North American Conference on Mycorrhiza University of Florida, Gainesville, Florida, May 3-8, 1987. pp. 364.
- Taube Baab, H. and Baltruschat, H. 1996. Productivity of strawberry (fragaria x ananassa Duch.) plants following inoculation with VA mycorrhizal fungi. *Erwerbsobstbau* 38(5):144-147.
- Tewari, L., Johri, B.N. and Tandon, S.M. 1993. Host genotype dependency and growth enhancing ability of VA-mycorrhizal fungi for *Eleusine coracana* (finger millet). *World Journal of Microbiology Biotechnology* 9(2):191-195.
- Thaper, H.S., Uniyal, Kamal and Uniyal, K. 1990. Survey of native VAM fungi of saline soil of Haryana state. *In: Current trend in myorrhizal research*. (eds. B.L. Jalali and H. Chand). Proceeding of the National Conference on mycorrhiza. Haryana Agriculture University. Hisar, India, Feb.14-16, 1990. pp. 16-17.
- Thaper, H.S., Verma, R.K. and Uniyal, K. 1991. Survey of native VAM fungi of Sodic soil of Haryana state. *Indian forester* 117(12):1059-1069.
- Thapar, H.S., Vijyan, A.K. and Uniyal, Kamla 1992. Vesicular arbuscular mycorrhizal association and root colonization in some important tree species. *Indian Forester* 118(3):207-212.
- Tinker, P.B. 1980. Role of rhizosphere microorganism in phosphorus uptake by plants. *In: The Role of Phosphorus in Agriculture*. (eds. Khasawneh, F.E., sample, E.C. and Kamprath, E.J.). American Society of Agronomy, Madison, wisc. pp. 617-647.
- Tommerup. I.C. 1983. Spore dormancy in vesicular arbuscular mycorrhizal fungi. *Trans. Br. Mycol. Soc.* 81:37-45.

- Trappe, J.M. 1977. Biogeography of hypogeous fungi: Trees, mammals and continental drift. *In: Abstr. 2nd Int. Mycol. Congr. Inc.* (eds. H.E. Bigelow and E.G. Simmons). University of South Florida, Tampa. pp. 675.
- Trappe, J.M., Molina, R. and Castellano, M. 1984. Reactions of mycorrhizal fungi and mycorrhiza formation to pesticides. *Ann. Rev. Phytopathol.* 22:331-359.
- Trappe, J.M. and Schenck, N.C. 1982. Taxonomy of the fungi forming endomycorrhizae. A. Vesicular-arbuscular mycorrhizal fungi (Endogonales). *In: Methods and Principles of Mycorrhizal Research* (ed. N.C. Schenck). American Phytopathological Society Publication, St. Paul, MN. pp.1-10.
- Trinick, M.J. 1977. Vesicular arbuscular infection and soil phosphorus utilization in *Lupinus* spp. *New Phytol*. 78:297-304.
- Udaiyan, K., Sugavanam, V. and Manian, S. 1996. Effect of formaldehyde fumigation and fytolan drench on VAM fungi and nodulation in some leguminous forest tree seedling in India. *Pertanika Journal of Tropical Agricultural Science* 19(1):33-41.
- Vasuvat, Y., Wadisrisak, P., Toomsen, B., Nopamornbodi, O., Thamsurakul, S., Thananusont, V. and Boonkerd, N. 1987. Interaction between mycorrhizal fungi and cowpea rhizobia on peanut cultivar Tainan-9 in Thailand. *In: Proceedings of the Seventh North American conference on Mycorrhiza* (eds. D.M. Sylvia, L.L. Hung and J.H. Graham). University of Florida, Gainesville, Florida, May 3-8, 1987. pp. 364.
- Verma, R.K., Khatri, P.K., Kunhikannan, C. and Totey, N.G. 1999. Comparative account on ground flora, soil microflora and fauna under plantation on bhata land. *Environment and Écology* 17(4):899-906.
- Vijaykumar, B.S. and Bhiravamurthy, P.V. 1999. Selection of efficient indigenous local VAM fungi for improving the groundnut crop in semi-arid tropical soils of Anantapur district, Andhra Pradesh. *In: Proceedings of the National Conference on Mycorrhiza* (ed. S. Singh). Bhopal, India, March 5-7, 1999.
- Walker, C. 1983. Taxonomic concepts in the Endogonaceae: Sproe wall characteristics in species description. *Mycotaxon* 18:443-455.
- Walker, C. 1987. Current concepts in the taxonomy of the Endogonaceae. In: Mycorrhizae in the Next Decade: Practical Applications and Research

- *Priorities* (eds. D. M. Sylvia, L.L. Hung and J.H. Graham). University of Florida Publication, Gainesville, Florida. pp.300-302.
- Walkley, A. and Black, I.A. 1934. Rapid titration method of organic carbon of soills. *Soil Sci.*, 37:29-33.
- Warner, A. and Mosse, B. 1980. Independent spread of vesicular arbuscular mycorrhizal fungi in soil. *Trans. Br. Mycol. Soc.* 74:407-410.
- Widiastuti, H. and Toruan, Mithuis. 1992. Response of selected *Leucaena* cultivar to *Rhizobium* and VAM fungi inoculation on acid soil. *Menara Perkebunan* 60(4):158-162.
- Wilkinson, L. 1996. SYSTAT 6.0 for Windows. SPSS Inc., Chicago.
- Wilson, J.M. 1984. Comparative development of infection by three vesicular arbuscular mycorrhizal fungi. *New Phytol.* 97:413-426.
- Wilson, J. M. and Trinick, M. 1982. Factors affecting the estimation of numbers of infective propagules of vesicular arbuscular mycorrhizal fungi by the most probable number method. *Aust. J. Agric. Res.* 22:73-81.

Appendix

Appendix –I

Meteorological data of NRCAF, Jhansi during experimental period

Months	Temper	ature (°C)	Relative l	numidity (%)	Rainfall	
	Maximum	Minimum	Forenoon	Afternoon	(mm)	
July, 2003	34.2	25.4	89	61	192.5	
August, 2003	32.6	24.7	94	70	177.0	
September, 2003	30.0	23.7	97	78	673.0	
October, 2003	33.0	16.3	88	47	0.000	
November, 2003	28.9	10.9	88	47	0.000	
December, 2003	23.9	8.2	91	51	0.212	
January, 2004	19.6	6.3	95.2	56.2	018.0	
February, 2004	27.7	8.4	92.5	45.5	0.000	
March, 2004	36.7	15.5	72.4	25.6	001.8	
April, 2004	39.9	21.2	58.7	26.0	0.000	
May, 2004	42.2	27.2	55.2	34.4	001.2	
June, 2004	36.7	26.4	75.2	47.2	069.7	
July, 2004	28.6	25.6	68.0	54.4	175.4	
August, 2004	32.9	24.1	90.2	63.7	151.5	
September, 2004	32.1	23.2	90.0	56.7	043.3	
October, 2004	31.6	14.9	85.2	40.7	024.4	
November, 2004	30.3	10.3	81.2	28.5	001.2	
December, 2004	24.0	7.1	85.5	37.7	0.000	
January, 2005	21.6	6.2	90.6	45.4	002.04	
February, 2005	27.5	9.9	86.0	36.7	002.80	
March, 2005	31.1	15.0	76.5	31.2	037.20	
April, 2005	38.3	17.5	58.2	24.6	008.20	
May, 2005	43.1	24.0	47.2	28.5	00.00	
June, 2005	41.7	26.9	60.0	35.2	014.20	
July, 2005	32.6	25.2	90.6	68.2	014.60	
August, 2005	33.7	24.2	86.7	59.5	082.80	
September, 2005	33.3	24.0	90.7	64.5	075.50	
October, 2005	34.1	15.5	82.2	30.0	001.80	
November, 2005	30.1	10.0	82.2	24.5	00.00	
December, 2005	24.0	5.2	90.2	37.2	001.20	

January, 2006 24.1 6.2 90.8 39.6 February, 2006 31.6 11.7 87.3 38.5	000.0
	0.000
14.1 0000	
March, 2006 31.8 14.1 84.5 43.0	006.1
April, 2006 40.0 19.4 62.4 25.2	000.2
May, 2006 41.8 25.6 61.6 34.8	013.1
June, 2006 39.0 26.8 68.0 13.3	013.4
July, 2006 32.9 25.7 87.0 67.2	023.7
August, 2006 32.0 24.4 89.5 67.5	023.3
September, 2006 34.8 22.8 86.3 50.5	001.9
October, 2006 34.8 18.0 77.8 35.5	0.000
November, 2006 29.9 11.8 85.3 33.5	0.000
December, 2006 25.6 8.5 84.0 39.3	001.2

INVAM WORKSHEET

Name	************	Date
Slide l	abel in	formation
Specir	nen ten	tative identification ————————————————————————————————————
I.		of these observations can be made with the dissecting scope but measurements should be made with a compound scope. Spore color: 1) In water 2) In mountant
	В.	Mountant used: PVL PVLG Other Spore diameter:
		For globose spores: Range um Mean um
		For irregularly-shaped spores: 1) Length: Range um Mean um 2) Width: Range um Mean um
	C.	Composite spore wall thickness (determined on intact spores if possible) ———— um
	D.	Attachment present? Yes No if no, go to <u>E</u> . 1) Hyphal terminus (= soporiferous saccule) present? Yes No 2) Bulbous suspensor (= sporogenous cell) present? Yes No 3) Hypha(e) present? Yes No
	E.	Spore contents: 1) Globular 2) Reticulate 3) Granular 4) Other
	F.	Spore with mantle or other surface hyphae? YesNo if no, go to G. 1) Width of hyphae um 2) Color of hyphae 3) Hyphae sinuous? Yes No

G.	Spores formed within the roots? Yes No
H.	Auxiliary cells present? Yes — No — If no go to I I If yes, check which applies: 1) Knobby — 2) Digitate — 3) Coralloid — 4) Echinulate _ 5) Spiny _ 6) Pigmented _ If pigmented, indicate color — —
I. J.	Sporocarp present? Yes No if no, go to <u>J</u> . 1) Sporocarp diameter 2) Peridium present? Yes No if yes, indicate color Additional comments
K.	Determine the genus of your specimen Genus Go to 1, 2, or 3, then II.
1)	For Gigaspora or Scutellospora: a. Bulbous suspensor (=sporogenous cells) dimensions: Widthµm Lengthµm b. Subtending hyphae (= sporophore hyphae) septate? Yes No c. Surface ornamentation on spore present? YesNo Description d. Germination shield present? YesNo
2)	For Acaulospora or Entrophospora: a. Hyphal terminus (= soporiferous saccule) present? YesNoif no, go to II b. Hyphal terminus collapsed? YesNoif yes, go to II c. Terminus dimension (diameter or length and width)µm d. Description of terminus contents (color; content appearance, e.g., granular, reticulate, globular; texture, e.g., smooth, rough, flaky)
	e. Hyphal length between spore and terminusµm f. Hyphal diameter at point of spore attachmentµm g. Pore diameter on spore at point of attachmentµm h. Cicatrix (Hyphal attachment scar) present? YesNo

	3. For Glomus or Sclerocystis
	a. Pore occluded? YesNo
	b. Pore diameterµm
	c. Presence of a septum at the pore? YesNoIf no, go
	to $\underline{\mathbf{d}}$.
	Protruding septum? YesNo
	d. Hyphal width adjacent to spore wallµm
	e. Number of attachments per spore
	f. Outer wall of hyphae contiguous with outer wall of spore?
	YesNo
	g. Type of attachment: (check all that apply)
	(1) straight (2) recurved (3) funnel-shaped
	(4) branched (5) septate (6) constricted
	(7) swollen (8) other:
	(7) SWOTICH (0) OUTCO
II.	Make these observations on broken spores with a compound
	microscope.
	A. Number of wall groups in the spore wall
	B. Width of each wall group:
	$A = \mu m B = \mu m C = \mu m D = \mu m E = \mu m$
	C. Number of walls within each group:
	A= B= C= D= E=
	D. Type of wall(s) within each group:
	$A = A \text{ mornhous} \qquad \text{Well Group } A = A \text{ mornhous}$
	A= Amorphous Wall Group A = C= Coriaceous
	E= Evanescent (ephemeral) B =
	L= Laminate
	M=Membranous C =
	P= Hyphal peridium
	U= Unit V= D-man din =
	X= Expanding
	$\mathbf{E}=\mathbf{E}$
	Walls ornamented or beaded are indicated by a subscript ₀ or _b respectively, under the wall type.
	Walls difficult to see are shown by * superscript over the wall
	type.
	E. Wall reaction to Meltzer's reagent. Indicate positive (+) or
	negative (-) for each wall group. If positive, also indicate wall
	color and wall type affected.
	If other reagent or stains are used, record the spore wall
	reaction as for Meltzer's reagent.
	요하는 물로 마시아 막고 있다. 아이트 아름은 아이트 이 모든 사람, 하는 아름도 먹는 뜻을 다듬었다.

в.							
C.							
D.							_
E.							
F.	Using the murograph.	information	from	section	II, c	onstruct	a
G.	Additional c	omments:					

Hoagland Solution (for plant cultures)

Solution no. 1	g/L
KH ₂ PO ₄	0.136
KNO ₃	1.02
Ca(NO ₃) ₂	0.492
$MgSO_4$ $7H_2O$	0.49
Solution no. A	mg/L
H ₃ BO ₃	2.86
MnCl ₂ .4H ₂ O	1.81
ZnSO ₄ .7H ₂ O	0.22
CuSO ₄ .5H2O	0.08
$H_2MoO_4H_2O$	0.09

Solution no. B

Dissolve 26.1g ethylene di-amide tetra-acetic acid in 268 ml of 1 N KOH. Add 24.9g FeSO₄ .7H₂O and dilute to one litre. Aerate overnight to produce stable ferric complex. The pH of solution should be about 5.5.

Add 1 ml of solution A to 1 litre solution 1.

Add 1ml of solution B to it. Adjust the pH to 6 with 0.1 N H₂SO₄.

Densities of organisms estimated by the dilution method

X				Number of	of levels (s))		
	4	5	6	7	8	9	10	11 o
					<u> </u>			more
0.4	.757	.773	.781	.785	.787	.788	.789	.789
0.6	.622	.640	.649	.653	.655	.656	.657	.657
0.8	.537	.556	.566	.571	.573	.574	.575	.575
1.0	.479	.500	.511	.516	.518	.520	.520	.521
1.2	.437	.461	.472	.478	.480	.482	.482	.483
1.4	.406	.432	.444	.450	.453	.455	.456	.456
1.6	.381	.411	.424	.431	.435	.436	.437	.438
1.8	.361	.394	.410	.417	.421	.423	.424	.425
2.0	.344	.382	.399	.408	.412	.414	.415	.416
2.5		.358	.382	.394	.399	.402	.403	.405
3.0			.370	.386	.394	.398	.400	.402
3.5				.379	.390	.396	.399	.401
4.0					.386	.394	.397	.401
4.5						.390	.396	.401
5.0							.394	.401
								.401*
<i>y</i> 7.0								.399
6.0								.397
5.0							.394	.394
4.5						.390	.390	.390
4.0					.386	.386	.386	.386
3.5				.379	.379	.379	.379	.379
3.0			.370	.370	.370	.370	.370	.370
2.5		.358	.356	.356	.356	.356	.356	.356
2.0	.344	.334	.334	.334	.334	.334	.334	.334
1.8	.327	.323	.323	.323	.323	.323	.323	.323
1.6	.311	.309	.309	.309	.309	.309	.309	.309
1.4	.293	.292	.292	.292	.292	.292	.292	.292
1.2	.271	.271	.271	.271	.271	.271	.271	.271
1.0	.245	.245	.245	.245	.245	.245	.245	.245
0.8	.212	.212	.212	.212	.212	.212	.212	.212
0.6	.167	.167	.167	.167	.167	.167	.167	.167
0.4	.101	.101	.101	.101	.101	.101	.101	.101

Ten fold (Three or more levels)

x	:<1		x>1,>2			<i>y</i> .	<2	
x	K	x	K	у	K	у	K	у
		.0	.763	.0	.761	2.0	.744	1.0
		.1	768	.9	.766	.1.9	.744	0.9
		.2	.768	.8	.764	1.8	.734	0.8
		.3	.760	.7	.755	1.7	.712	0.7
0.4	.761	.4	.747	.6	.741	1.6	.684	0.6
0.5	.740	.5	.736	.5	.729	1.5	.658	0.5
0.6	.733	.6	.733	.4	.724	1.4	.638	0.4
0.7	.736	.7	.736	.3	.726	1.3		
0.8	.744	.8	.744	.2	.732	1.2		
0.9	.753	.9	.753	.1	.739	1.1		
1.0	.763	.0	.763	.0	.744	1.0		

When x>1 and y>2 enter the table with the decimal part of x or y only.

Four-fold

X]	Number of level	S
	4	5	6 or more
0.4	.704	.706	.707
0.6	.615	.617	.618
0.8	.573	.576	.577
1.0	.555	.558	.559
1.5	.545	.551	.553
2.0	.537	.548	.551
2.5		.545	.552
			.552*
y			
3.5			.550
3.0			.548
2.5		.545	.545
2.0	.537	.537	.537
1.5	.522	.522	.522
1.0	.488	.488	.488
0.8	.464	.464	.464
0.6	.431	.431	.431
0.4	.375	.375	.375

Calculate the mean fertile level x, and the mean sterile level y, where x is the number of fertile plates/number of cultures at each level (n), and x + y is the number of levels. Enter the table with x or y, as indicated, and determine the corresponding value of the tabular entry K. When x and y fall outside the

tabulated range use the value marked with an asterisk (*). The estimate of the number, λ of organisms in the quantity of the medium used for one culture at the highest concentration is then given by $\log \lambda = x \log a$ -K, where a is the dilution factor. The average value of the variance of the mean fertile level is I $\log 2$ /(n $\log a$) and the average value of the variance of $\log \lambda$ is 1/n *($\log 2 \log a$).

Thus:

Two-fold

Four-fold

 $\frac{\log \lambda}{V(x)} = 0.30103 \ x - K \\
= 1/n \\
= 0.091/n \\
\downarrow \\
\frac{\log \lambda}{V(x)} = 0.60206 \ x - K \\
= 1/2n \\
= 0.201/n$

Ten fold

 $\frac{\log \lambda}{V(x)} = x-K$ =0.301/n

Appendix-V

Soil pH, EC and percent organic content of the soil samples taken from basins of Aonla, Ber, Chironji and Lasoda.

Treatments		pН		EC (μS cm ⁻¹)		% OC	
	Mean	Range	Mean	Range	Mean	Range	
Aonla (Emblica officinalis Gaertn.)							
Varieties							
Chakaiya	5.85	5.39-6.11	43	31-55	1.58	1.34 - 2.22	
Kanchan	6.15	5.78-6.45	28	43-52	1.36	0.78-1.91	
Krishna	6.08	5.96-6.24	39	28-45	1.18	1.14 - 1.31	
NA-7	5.94	5.75-6.12	38	33-49	1.12	0.93 - 1.42	
Soil types							
Black soil	5.88	5.26-6.32	49	28-61	1.53	0.78 - 2.74	
Lateritic soil	5.93	5.57-6.44	39	33-49	1.19	0.91 - 1.40	
Red soil	5.94	5.75-6.12	38	33-49	1.20	1.09 - 1.42	
Upland v/s lowland plants							
Waterlogged plants	6.59	6.18-6.86	61	56-66	1.42	0.93 - 1.81	
Upland plants	6.08	5.96-6.24	39	28-45	1.80	1.39 - 2.17	
Agroforesrty							
With wheat	6.34	6.02-6.77	53	45-59	1.42	0.93 - 1.81	
Without wheat	5.78	5.26-6.1	33	25-42	1.00	0.67 - 1.29	
Other sites							
Baruasagar, Nagar Palika	7.33	7.15-7.39	231	109-525	2.94	1.71-4.65	
Katili	6.29	5.86-6.76	50.25	41-71	1.06	0.62-1.40	
Ber (Zizyphus mauritiana Lamk.)							
Varieties							
Banarsi karaka	5.94	5.71-6.16	62	26-141	0.91	0.62-1.13	
Desi	6.03	5.7-6.24	33	28-41	0.74	0.57-0.93	
Gola	6.05	5.78-6.32	31	22-37	1.09	0.88-1.24	
Seo	6.09	5.62-6.32	36	29-42	0.76	0.26-1.55	
Wild relatives							
Ghot	6.17	5.65-6.8	48	34-57	1.17	0.91-1.60	
Jharberi	6.95	6.38-7.86	85	67-99	1.63	0.36-2.79	
Makor	6.13	5.66-6.50	44	29-44	1.75	1.39-2.12	
Lasoda (Cordia myxa Spr.)							
Sites							
Nareta, Datia	7.82	7.64-8.06	133	88-176	0.59	0.65-0.88	
NRCAF, Field 1	5.94	5.73-6.09	49	38-56	1.39	1.14-165	
NRCAF, Field 2	5.61	5.39-5.77	46	36-53	1.37	1.29-1.55	
Chironji (<i>Buchanania lanzan</i> Roxb.)						
Sites							
Jakhlon Forest Nursery, Lalitpur	7.0	6.65	68	51-91	1.16	1.03-1.24	
Nilkanthh Temple, Lalitpur	6.72	6.38-6.93	60	42-74	1.24	1.03-1.45	

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